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THESIS

A MAINTENANCE SUPPORT MODEL

by

Stephen P. Peterson

December 1984

Thesis Advisor: Samuel H. Parry

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This thesis develops a general structure of an explicit, sequential event model of maintenance support at division level. The model is intended as an initial stage model for subsequent use in tandem with a combat feeder model to provide necessary insight into development of a largely implicit, variable resolution, hierarchical maintenance support model as part of the Corps level systemic Airland Research model.

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Three key maintenance support planning processes which are crucial to timely and effective combat maintenance support are formulated into pseudo code algorithms: workload scheduling and allocation (triage), workload prioritization, and maintenance time criteria (MTC) updating.

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A Maintenance
Support Model

by

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Captain, United States Army
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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

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December 1984

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I. INTRODUCTION

The U.S. Army's concept of the nature of future armed conflict is defined within the framework of the Airland Battle Doctrine. A major premise of this doctrine is the need for interdiction and deep attack of the enemy's rear areas in order to slow his forward flow of forces and enable outnumbered Allied forces to fight the enemy piecemeal. However, few current combat models adequately represent this interdiction battle of sparsely populated rear areas and the effects of the command and control of forces necessary to execute such interdiction.

Currently research is being conducted at the Naval Postgraduate School concerning modelling methodologies for development of an Airland Research Model [Ref. 1]. This research is still in the conceptualization stage of development but has identified the following five major methodology research objectives:

1. The investigation of a methodolcgy for development of combat simulations which may be operated either in a systemic or open (man-in-the-loop) mode.
2. The use of rule-based systems to represent command and control (C^2) and related processes.
3. The development of a generalized network methodology and multi-dimensional coordinate system to represent terrain, transportation systems, communications systems, and combat assets. A hierarchical structure is hypothesized for this generalized network.
4. Development of a generalized value system applicable to all essential features of the research simulation.
5. The investigation of methodology for aggregation and disaggregation.

At present the direction of the research regarding the first objective is development of the model using a systemic mode architecture. With such an approach the specific decision points in the simulation must be identified and algorithms developed to represent those decision processes. Subsequent research can then utilize human interaction (man-in-the-loop mode) at selected decision points without sacrificing audit trail capability.

The final goal of the research is the development of a Corps level combat model with an architecture of as many prescriptive, analytical methodologies as appropriate for investigation of more optimal methods of planning and executing the AirLand battle.

An inherent need of such a representation of Corps level combat requires an ability to capture a realistic assessment of the number of combatant weapon systems that are mechanically available to fight at any point in time of the battle. A model of the vertical maintenance support processing of mechanically unavailable weapon systems and their return to combat provides such an assessment capability.

A model of the maintenance support vertical function can take one of two general forms: an explicit, sequential event model of the maintenance support functions or an implicit model using characteristic stochastic processes to represent maintenance support functions. In keeping with the goal of implicit, prescriptive methodologies for the Airland Research Model, the final form of the vertical maintenance support model should be a largely implicit model.

The development of an implicit model of maintenance support requires a thorough knowledge of its functioning in combat. However, the current state of knowledge of maintenance functioning in combat is insufficient to meet the needs for development of such an implicit model. Thus, in order to develop an implicit model of maintenance support for the Airland Research Model, initial research must be conducted with explicit maintenance support models to develop a better understanding of maintenance functioning and to identify the characteristic stochastic processes.

The purpose of this thesis is the development of a general structure of an initial stage, hierarchical maintenance support model using an explicit, sequential event methodology. The effort is focused upon development of the explicit maintenance support planning processes.

This initial stage maintenance support model can then be used in tandem with an explicit combat model or crude combat feeder model to gain a better understanding of the maintenance support system in combat and eventually lead to the development of an appropriate maintenance support model for the Airland Research Model.

The scope of this thesis is limited to investigation of the functions and rule-based decision logic of maintenance support to include recovery and evacuation, repair, and repair parts supply at division level and below. It is also limited to examination of ground support and missile maintenance only, which excludes aviation, textile, and airdrop equipment maintenance. However, missile maintenance is limited to land combat and light air defense missile systems. Several rule-based maintenance decision algorithms are proposed for further research.

The proposed structure of the initial stage explicit maintenance support model is original work. The concepts of the model structure and the planning process algorithms were not extracted from existing documents or models. They were developed from scratch and in some cases the decision logic formulated from the author's experience and expertise in maintenance support as specific decision criteria have not been stated in any U.S. Army doctrinal publication.

This thesis is organized into five chapters and three appendices.

Chapter 2 presents background information about the role of maintenance support, its organization and structure within the division, and its functional subtasks. Additionally, all maintenance entities within the division and their missions, locations, and attributes are identified. Then a maintenance operations interconnectivity and entity hierarchy is formulated and a list of maintenance demands attributes presented.

Chapter 3 discusses several key modelling issues necessary for determining how to structure the initial stage maintenance support model. Short descriptions of the maintenance models of two current division or theater level models are presented to provide a perspective on current methodologies of modelling combat maintenance support. Then the issues of the maintenance support model's study objectives, method of representation, level of resolution, and data sources are examined and discussed.

Chapter 4 describes the general design of the maintenance support model. The general planning and execution processes of the model are identified and characterized. The separate components of the model are identified and formulated into a general model structure. Finally, the triage - maintenance demand scheduling, workload prioritization, and maintenance time criteria update planning processes are discussed in detail. This detail is presented via a Software Documentation Design Language (SDDL) description of the process algorithms.

In chapter 5, a summary of the thesis is presented and recommendations for the direction of further research on maintenance support modelling are given.

Appendix A is a glossary of operational terms and acronyms for the reader unfamiliar with the U.S. Army maintenance support terminology.

Appendix B presents a listing of definitions of the variables and lists used in the planning process algorithms given in Appendix C.

Appendix C gives the detailed "pseudo-code" algorithms for the three specified planning processes.

II. BACKGROUND

A. INTRODUCTION

The purpose of this chapter is to present background information pertaining to the function and organization of maintenance at divisional level in the U.S. Army. This includes discussion of maintenance support's role on the battlefield; primary sub-tasks; organizational hierarchy; identification of maintenance entities and their missions; maintenance entity general attributes; and maintenance command and control structure. The U.S. Army's Division 86 maintenance support serves as the example since all other U.S. Army combat organizations have a similar structure and role for maintenance support.

B. MAINTENANCE SUPPORT OVERVIEW

1. Definition

Maintenance is defined to be all action taken to retain materiel in a serviceable condition or to restore it to serviceability [Ref. 2: p. 7-1]. This function has become an increasingly more critical one in combat as demonstrated by the rapid loss rates incurred by both sides in the 1973 Arab-Israeli War due to the increased weapon system lethalities. In such high intensity combat maintenance support's major role is sustaining combat, since war reserves are expected to be austere.

Maintenance support additionally is closely interrelated with other logistical functions, especially supply and transportation. In particular supply and maintenance work in tandem to return the maximum amount of weapon systems to combat through extensive use of transportation support. In this context the decision to trade off repairs for replacements or vice versa is based upon the critical factors of available time and resources [Ref. 3: p. 5-1].

2. Maintenance Support Sub-tasks

Ground support maintenance can be divided into five general sub-tasks: recovery and evacuation, repair of equipment, repair parts supply, command and control (C^2), and tactical. These divisions are made primarily for clarity and ease in understanding the flow of maintenance support operations. However, all of these sub-tasks are interrelated and cannot function alone on the battlefield.

Recovery is distinguished from evacuation primarily by the organization performing the operation. Recovery operations remove equipment from forward combat areas to locations further to the rear for repair. Each unit in the division is responsible for recovering its own damaged equipment. Recovery may be to the unit's field trains for immediate repair or to a collection point for repair by a supporting maintenance unit.

Evacuation operations move equipment from collection points to locations further to the rear for repair, cannibalization, or further evacuation. Evacuation operations are coordinated by maintenance, supply, and transportation elements since evacuation operations impact upon the functions of all three types of support. In this context evacuation operations are conducted only by combat service support (CSS) units and not by combat or combat support units.

The repair sub-task includes inspection and classification of damaged equipment, restoration of damaged equipment to serviceability (repair), testing of equipment, preventive maintenance, and modification of equipment. The repair process is a multistaged one which begins with initial damage assessment and progresses through a sequence of repair, recovery, and repair parts supply functions and ends with the return of a weapon system to combat.

The repair parts supply sub-task includes direct exchange (DX), operational readiness float (ORF), normal receipt, storage, and issue of repair parts, repair parts management, and controlled exchange or cannibalization. Controlled exchange is the removal of serviceable parts from unserviceable, economically repairable equipment for instant use in restoring a like item to serviceable condition. Cannibalization is the authorized removal of serviceable and unserviceable assemblies from unserviceable, uneconomically repairable or excess end items of equipment authorized for local disposal. Both controlled exchange and cannibalization require the interaction of mechanics to obtain the repair parts.

The command and control sub-task consists of all actions necessary for management and leadership of maintenance elements. It is closely interrelated with all maintenance missions and functions and is the key to successful maintenance support. Responsive and timely C^2 is essential to mission success.

The tactical sub-task consists of all actions which do not contribute directly to the maintenance effort and its management and control. It includes tactical movements, relocation decisions, unit site selection and reconnaissance, and rear area security (RAS) and rear area combat (RAC). RAS and RAC, however, are not examined in this thesis.

3. Levels of Maintenance

The U.S. Army's maintenance support system currently consists of four levels of maintenance: organizational, direct support (DS), general support (GS), and depot [Ref. 4: p. 2-4]. Each level is a different category and contributes differently to the overall system. Although only the organizational and direct support levels are included within the U.S. Army's Division 86 structure, Corps level DS and GS units are often deployed forward into division areas for quicker support.

As part of the U.S. Army's ongoing force structure modernization, a three level maintenance concept is to be implemented. The only impact this implementation has upon the following discussion of levels of maintenance is the removal of the GS level of maintenance from the Corps force structure. Each level of maintenance is discussed below.

Organizational maintenance is normally provided by the unit owning the equipment. It is performed at both the company and battalion level. Its role is to keep equipment operating, identify failures and make minor repairs, perform necessary equipment services and other preventive maintenance, perform recovery of equipment to the next higher level of support and repair, and provide repair parts supply. It is characterized in combat as mission essential maintenance only (MEMO) which reduces the number of maintenance tasks required for serviceability restoration to only those essential for a combat system to perform its primary mission.

Direct support maintenance is provided by maintenance units tailored to the forces they support. The primary mission of these DS maintenance units is the provision of maintenance support to specifically designated combat units. All ground support and missile DS maintenance units in the division are assigned to the Division Support Command (DISCOM) with a role of repairing equipment and returning it to the user, operation of maintenance collection points (MCP), backup recovery support, evacuation of equipment to higher levels of support, and supplying repair parts to their supported units. DS level repairs in general require more skilled mechanics and special tools than organizational maintenance. DS level is also the first level of repair at which cannibalization occurs.

General support maintenance is provided by maintenance units assigned to Corps level or higher. At division level, GS maintenance teams can often be found in the division rear area providing battle damage assessment support or specific GS repairs of combat critical equipment in response to specific division requests. These teams are temporarily placed under the operational control of the DISCOM.

4. Fix Forward Operational Concept

The fix forward operational concept involves the positioning of maintenance assets of the U.S. Army in the field as close to the operating combat forces as the tactical situation permits [Ref. 5: pp. 2-7]. This operational concept encompasses the use of three operational principles: forward deployment of mobile maintenance teams, use of battle damage assessment procedures, and time guidelines for repairs by level. A pictorial depiction of the fix forward operational concept is shown in figure 2.1 [Ref. 5: p. 5].

The first principle involves mobile maintenance teams from all levels - organizational, direct support, and general support - being deployed forward to provide supplemental maintenance to lower levels. By conducting repairs as close to breakdown sites as possible, the time consuming requirement for recovery and evacuation is minimized. Additionally critical repair parts are obtained quickly through extensive use of controlled exchange and cannibalization.

The second principle requires assignment of specially trained battle damage assessors (mechanics) to the mobile maintenance teams responsible for evaluation of the extent of damage and determination of recovery or evacuation decisions. Making these evaluations far forward enables maintenance support to avoid lengthy echelon by echelon recovery and evacuation by direct routing of damaged equipment to the appropriate repair facility or location.

The third principle is the use of repair time guidelines - maintenance time criteria (MTC) - at each maintenance level to avoid the buildup of large backlogs which can interfere with combat operations, especially at lower levels. The commander at each level establishes the MTC based upon guidance from higher headquarters, the tactical situation, maintenance backlog, personnel, tools, test equipment, and availability of repair parts. Although maintenance commanders at each level establish their MTC, they must closely coordinate it with the supported force combat commander.

5. Maintenance Support Control and Execution

Within the division, maintenance support is planned and controlled centrally at each hierarchical level; that is each level possesses a maintenance element responsible for planning and control. However in keeping with the fix forward operational concept, the execution of maintenance support is decentralized and spread throughout the division area. Such centralized control linked to decentralized execution requires extensive communications support and close, continuous coordination between all maintenance elements. In this context, C^2 is a major factor in achieving successful maintenance support.

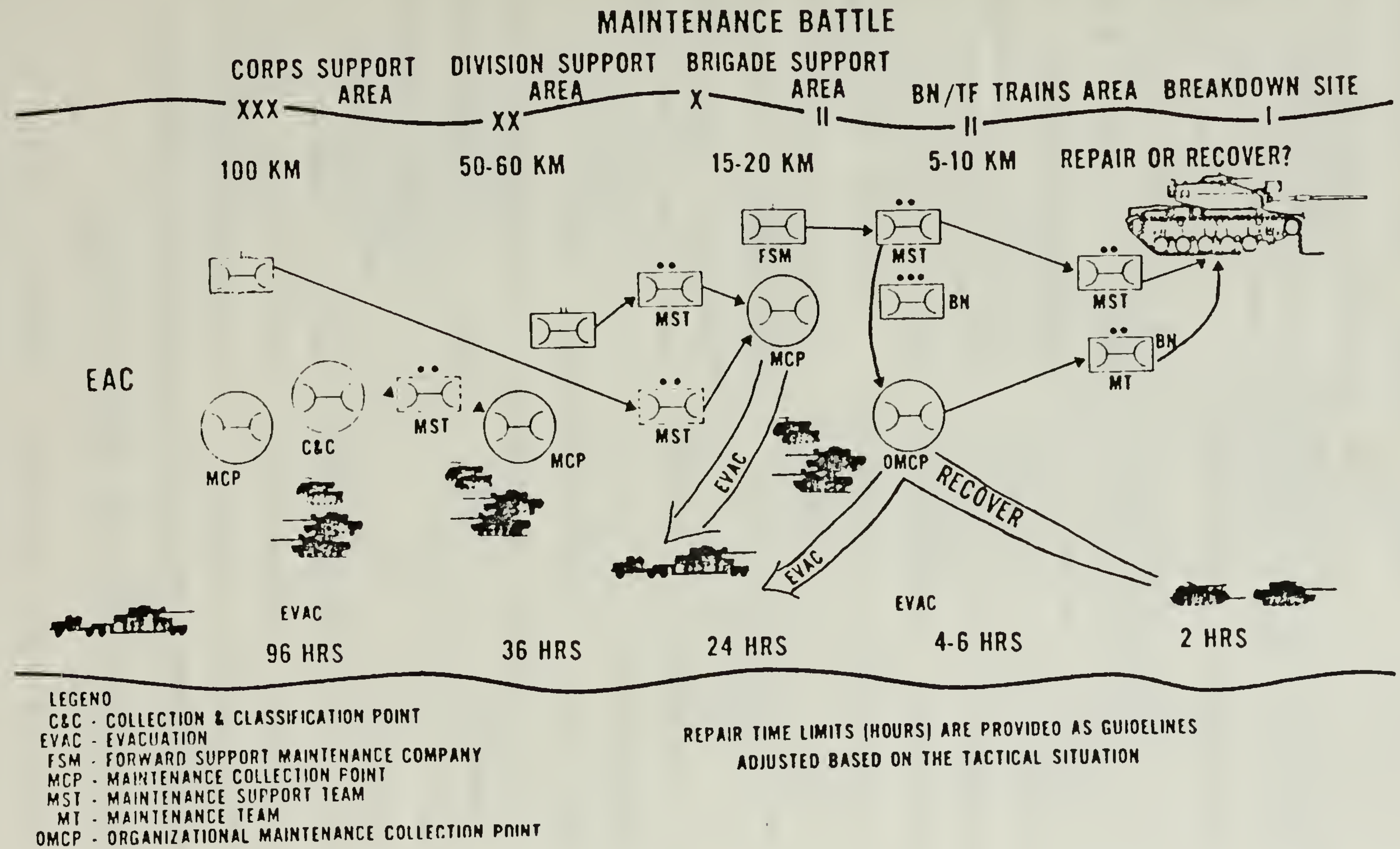


Figure 2.1 Maintenance Battle.

C. DIVISION MAINTENANCE SUPPORT ORGANIZATION AND STRUCTURE

1. Maintenance hierarchy

DS maintenance support within the division is specifically structured to provide dedicated support to each level of the maneuver unit hierarchy. It is a tiered structure wherein each maneuver hierarchy level is supported by one primary maintenance element which is in a direct support role. The relationship between the maintenance element and the maneuver unit it supports is similar to that of operational control (OPCON) yet each maintenance element is actually simultaneously retained under the direct command and control of its superior maintenance headquarters.

Organizational maintenance support within the division is also hierarchical in nature, however maintenance elements are organic to the maneuver units and exist solely at battalion and company level. Every battalion and separate company in the division possesses its own organic organizational maintenance element and exercises direct command and control of it.

The interface of DS maintenance and organizational maintenance occurs between battalion or separate company maintenance elements and the specific DS maintenance elements providing them support. This interface is usually limited to DS maintenance level repairs, backup recovery or evacuation support, and repair parts supply. However organizational level repair assistance is often sought from the supporting DS maintenance element. A pictorial depiction of the division maintenance hierarchy is shown in figure 2.2.

2. Maintenance entities and their missions

Each hierarchical maneuver entity down through company level normally is provided a single primary maintenance entity responsible for its support in coordination

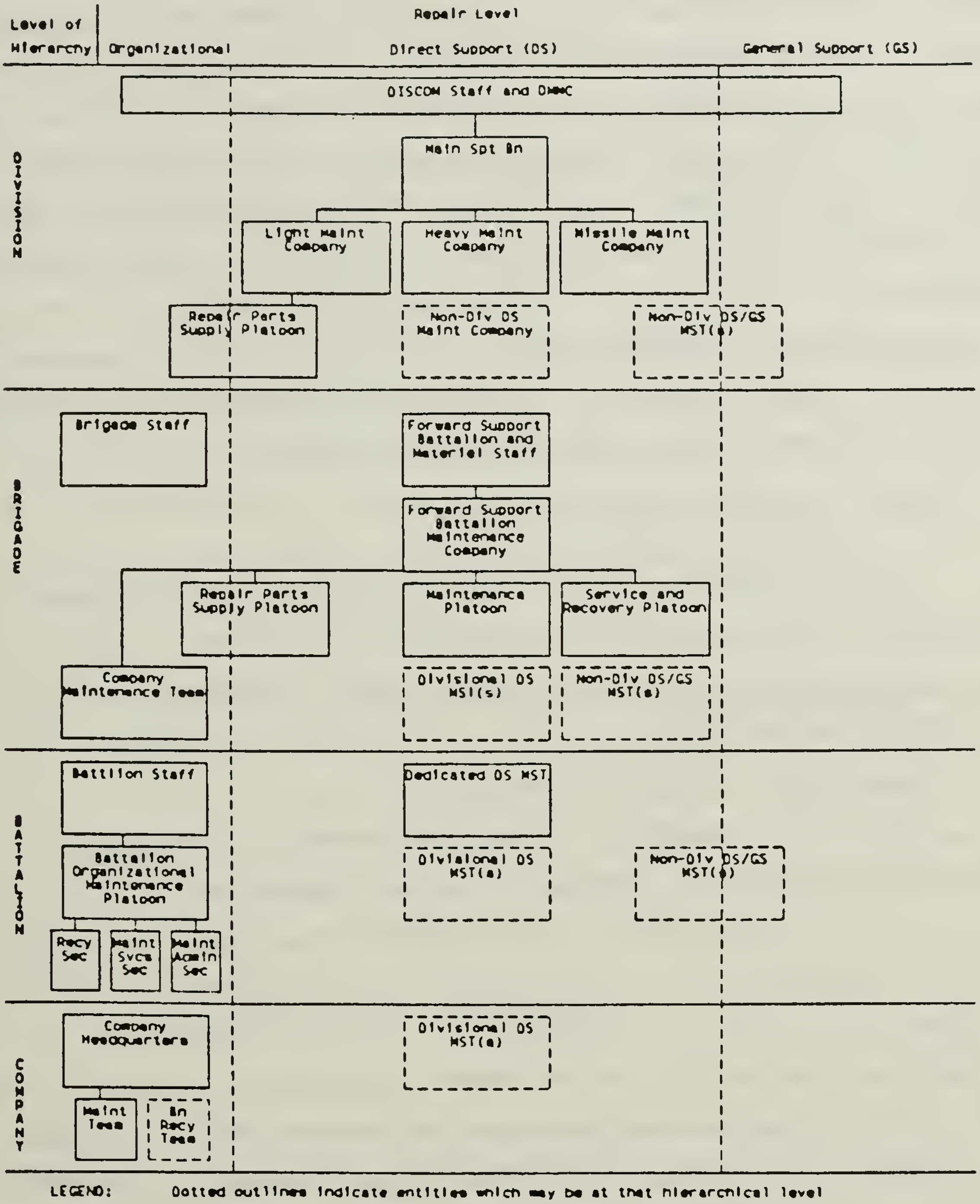


Figure 2.2 Maintenance Hierarchy.

with the maneuver unit command and control element. However during combat several other various type maintenance entities may also be present at a particular maneuver hierarchical level due to the pushing forward of maintenance entities in execution of the fix forward operational concept. These additional entities may range in size from a single recovery vehicle to a company sized element. Since the number of maintenance entities is variable, each maneuver hierarchical level's possible maintenance entities are discussed. Additionally each entity's composition and organization is tailored to the specific unit it supports. In this context the entities are discussed in a general structural nature with no specific composition by numbers and types of mechanics and equipment given.

a. Company level entities

At company level the following maintenance entities may be found during the course of battle:

1. Organizational maintenance team (organic or attached from battalion).
2. Supporting recovery team(s).
3. Supporting organizational maintenance team(s).
4. DS maintenance support team(s) (MSTs).

An organizational maintenance team is organic to separate companies but is attached to maneuver type companies from their parent battalion. All other type units in the division including DS maintenance units have an organic company level organizational maintenance team. This team may consist of these subelements: recovery, command and control, repair, and administrative. Its mission is the management of organizational maintenance for the company. It performs three primary tasks: repair of equipment and returning it to battle; limited battle damage assessment for recovery decision purposes; and coordination of equipment recovery or evacuation.

A maintenance sergeant commands the team in coordination with the company executive officer (XO) and first sergeant (1SG). The recovery element is usually at most a single recovery vehicle and crew. The repair element is variable in size but consists of several system mechanics with skills tailored for the specific weapon system types in the company. The administrative element is usually one or two clerks who maintain the company equipment maintenance records, provide repair parts and maintain the company prescribed load list (PLL), and prepare maintenance reports.

Additional recovery or organizational maintenance teams may be attached for specific tasks temporarily, particularly for reduction of workload backlogs, or may be conducting specific backup tasks requested by the company. Although these teams are present for specific missions and short periods of time, they are usually placed under the supported company's operational control until their tasks are finished.

MST's from the supporting DS maintenance element may also be pushed forward to company level for the conduct of quick DS level repairs or battle damage assessment when a large number of combat damaged equipment is generated. However these MST's are seldom placed under the operational control of the supported company.

b. Battalion level entities

At battalion level the following maintenance entities may be found during the course of battle:

1. Battalion organizational maintenance platoon.
2. DS maintenance support team(s) (MSTs).
3. Unserviceable Equipment Rally Point (UERP).

A battalion organizational maintenance platoon is organic to each battalion within the division and is the entity primarily responsible for maintenance operations at the battalion level. This platoon is responsible for the conduct and management of all organizational maintenance within the battalion or task force, if task organized. It may consist of the following subelements: platoon headquarters, maintenance administration section, recovery section, maintenance services section, and company maintenance teams. The platoon performs the following primary tasks: repair of equipment and its return to battle, battle damage assessment for recovery decision purposes, management and coordination of recovery and evacuation of the battalion's damaged equipment, repair parts supply and management of PLLs, coordination of any attached DS MSTs workload, backup support to company maintenance teams, coordination for DS maintenance support, and battalion maintenance workload management and reporting.

The battalion maintenance platoon is led by the Battalion Maintenance Officer (BMO) with the assistance of the Battalion Maintenance Technician (BMT) and Battalion Motor Sergeant. The BMO and Battalion XO manage the battalion's maintenance workload by setting priorities for repair and establishing the battalion MTC.

Each battalion maintenance platoon is organized and equipped with personnel and equipment tailored for support of the battalion's specific equipment composition. However, each section of the platoon performs the same essential tasks in any battalion. The maintenance administration section provides repair parts supply including DX items, manages the company PLLs, maintains the equipment maintenance records, and prepares maintenance reports. The recovery section provides recovery support to the battalion and lifting support to the maintenance services section. The maintenance services section conducts all organizational repairs, preventive maintenance, and other equipment maintenance actions at battalion level and is primarily responsible for repairing equipment in the unserviceable equipment rally point (UERP) and assisting company maintenance teams.

The battalion UERP is most often colocated with the battalion maintenance platoon in the battalion combat trains. However, on occasion the UERP may not be colocated for operational security or geographical reasons. In such a case the UERP is usually operated by the maintenance services section and controlled by the BMT. Most of the controlled exchange and repairs conducted within the battalion are performed at the UERP.

Normally a tailored MST from the supporting DS maintenance company is pushed forward for dedicated direct support to each maneuver battalion. Its primary missions are the conduct of battle damage assessment and quick DS level repairs. It assists in triage at the battalion UERP. Additional DS MSTs may temporarily be in a battalion's area for the conduct of specific repairs or backup support.

c. Brigade level entities

At brigade level the following maintenance entities may be found during the course of battle:

1. Forward Support Battalion (FSB) Maintenance Company.
2. DS or GS MSTs (from DISCOM or Corps).
3. Maintenance Collection Points (MCPs).

The FSB Maintenance Company is the maintenance entity primarily responsible for the conduct of DS and higher levels of maintenance operations in the brigade area. Its mission is the provision of DS maintenance support to all units assigned or attached to its supported brigade. Except for the DS MSTs of the company, all FSB maintenance companies are organized and composed similarly. Each DS MST is tailored for support of a specific type maneuver battalion. The company is composed of the following subelements: company headquarters, maintenance control section, service and recovery platoon, repair parts supply platoon, MSTs for each battalion in the brigade, and a maintenance platoon consisting of the communications-electronics, armament, power generation and engineer, missile, automotive maintenance sections, and organizational maintenance team.

A FSB maintenance company provides DS maintenance support to the brigade in two primary manners. MSTs which comprise a large portion of the company are deployed forward with each battalion sized unit for on-site rapid support and battle damage assessment. These MSTs are seldom recalled for consolidation at the company. All other DS repairs are performed in the Brigade Support Area (BSA) by the remainder of the company. This is accomplished via equipment recovery to the BSA by the owning units with most large items of equipment (weapon systems) being processed at a central MCP. Triage is performed at the MCP and weapon system disposition - repair or evacuate - is determined. This MCP is normally colocated with the company in the BSA.

The command and control of the company is provided by both the company headquarters and the maintenance control section. The maintenance control section is concerned primarily with control of DS maintenance and repair parts supply operations while the company headquarters is mainly concerned with tactical, logistical, and administrative control of company operations.

The repair parts supply platoon provides repair parts supply including DX items to both the company and the brigade organizational maintenance elements. It also manages the brigade level ASL (Authorized Stockage List) of repair parts and the brigade level ORF.

The service and recovery platoon provides allied trades (machining, welding, painting, et cetera) and recovery support to the company and backup allied trades and recovery support to brigade units. It also provides lifting support to the maintenance platoon as necessary.

The maintenance platoon provides DS repair of communications-electronics, automotive, armament, power generation, engineer, and missile equipment. It is also primarily responsible for the operation of the brigade MCP which may or may not be colocated with the company. This MCP is the focal point of the brigade level maintenance effort since the majority of weapon system repairs are processed for maintenance there.

The organizational maintenance team is organized similarly to those discussed under company level entities but tailored for support of the specific equipment of the FSB Maintenance Company.

In addition to the FSB Maintenance Company, DS or GS MSTs from DISCOM or Corps may be in the brigade area. These MSTs primarily serve to assist the FSB Maintenance Company in reducing the MCP backlog. However on occasion a backup DS or GS MST may be deployed forward for a specific on site repair task or may function as BDA teams at the MCP when a large backlog exists. These forward deployed MSTs are normally placed under temporary operational control of the FSB Maintenance Company for the duration of their mission.

Management of the brigade's organizational maintenance is the responsibility of the brigade staff.

d. Division level entities

The following maintenance entities may be found at the division level during the course of battle:

1. Main Support Battalion (MSB) maintenance companies-Light,Heavy, and Missile.
2. MSB Material Staff.

3. Division Material Management Center (DMMC).
4. DS or GS MSTs from Corps.

The entities primarily responsible for the conduct of DS maintenance operations at division level are the Light, Heavy, and Missile Maintenance Companies of the MSB. Each company provides commodity oriented DS maintenance support and are organized similarly to the FSB Maintenance Company but with subelements tailored for specific support of the commodities each supports.

The Light Maintenance Company provides DS repair support of small items or components including communications-electronics equipment, communications secure (COMSEC) equipment, power generation equipment, automatic data processing (ADP) equipment, and fuel and electric components and provides repair parts supply support to the entire division. It primarily conducts repairs at its location in the Division Support Area (DSA) on recovered or evacuated equipment from the division rear units or brigades. In addition it may conduct some repairs at the Division MCP or provide backup DS MSTs to the BSAs.

The repair parts supply platoon of the Light Maintenance Company provides repair parts supply support to all the DS maintenance companies in the division, non-brigade organizational maintenance elements, and the brigade ASLs and maintains the division ASL and ORF.

The Heavy Maintenance Company provides DS repair support of larger equipment including automotive, engineer, armament, and allied trades; provides recovery support and MSTs to battalion sized non-brigade units of the division, particularly the cavalry squadron and GS artillery battalion; operates the Division MCP(s); and provides DS MSTs to the FSB Maintenance Companies for backup support or BDA.

The Missile Maintenance Company provides DS missile maintenance support and missile repair parts supply support to the entire division for land combat and light air defense missile systems and equipment. It provides this support primarily by deploying MSTs to the division air defense battalion and cavalry squadron, supervising missile repairs in the FSB Maintenance Companies, and assisting with repairs at the Division MCP(s). However most component repairs are normally performed at the company's DSA location, since the majority of repairs require the use of the van mounted LCSS (Land Combat Support System) test equipment for diagnostic troubleshooting and inspection. There is only one LCSS in the company for support of the entire division which makes it an essential item for effective maintenance support of the division. The missile MSTs are deployed forward primarily for preventive maintenance purposes, early detection of maintenance requirements, and quick fix repairs requiring little troubleshooting.

The MSB Material Staff supervises the operations of the Light, Heavy, and Missile Maintenance Companies and manages the division's DS maintenance operations. It functions solely as command and control of DS maintenance operations.

The DMMC provides supervision of both the division's repair parts supply operations and the division's maintenance operations both organizational and DS or GS. Its primary functions are the management of the division's ASLs and the setting of maintenance priorities by weapon system.

e. Maintenance entity location

Maintenance entities are a portion of the combat service support (CSS) assets provided to combat entities and are an integral part of combat entities' unit trains. These unit trains are the total combat service support elements supporting a combat entity.

Unit trains are normally echeloned into combat trains which provide immediate response to the combat elements and the field trains which provide less immediate response. The combat trains are located well forward near the combat elements, whereas the field trains are located further rearward for better protection and proximity to main supply routes.

Both the combat and field trains function tactically as subelements of the combat entity being supported. Defensive and tactical movement operations are conducted by each of these echeloned trains independently and as composite entities. In this context, maintenance entities conduct tactical movements and rear area combat operations in conjunction with the trains to which they belong.

At the organizational maintenance level, company maintenance teams and battalion maintenance platoons are usually located in their supported combat entity's combat trains. Whereas, at the DS or higher maintenance level, maintenance entities are almost always located in the supported combat entity's field trains.

3. Attributes of Maintenance Entities

This section identifies the essential general attributes of maintenance entities which are required for maintenance support planning, execution, or decision making. Specific maintenance entities possess only a subset of these attributes based upon their missions and hierarchical level. Each attribute is required for at least one of the five maintenance sub-tasks identified in subsection B.2 of this chapter: command and control, recovery and evacuation, repair, repair parts supply, and tactical.

Each general attribute is classified as either inherent or state dependent. Inherent attributes are those which are fixed based upon the entity's organization and structure and never change unless the entity's organization and structure is changed. Entity identification and authorized personnel and equipment strengths are examples of inherent attributes. All other entity attributes which change based upon the current state of the entity are state dependent attributes.

Table I is a list of the primary attributes of maintenance entities matched to the applicable maintenance sub-tasks for which they are needed. Each sub-task is abbreviated and identified in the table legend which is at the bottom of the table. This list is not all inclusive but represents the essential attributes needed for modelling maintenance support.

4. Maintenance C^2 structure and interconnectivity

Command and control is defined as "the process of directing and controlling the activities of military forces in order to obtain an objective. It includes consideration of the physical means of its accomplishment - the communications, control centers, information gathering systems, and the staffs and facilities necessary to gather and analyze information, plan for what is to be done, and supervise the execution of what has been ordered" [Ref. 2: p. 3-2].

All maintenance elements are under the command and control of a specific superior element. However, this specific superior element is variable due to decentralization of execution and the pushing forward of support. As a result a maintenance element operates under any one of a possible set of command or support relationships at any point in time. The three common command and one common support relationships are explained in figure 2.3. Each of

TABLE I

General Maintenance Entity Attributes

Attributes	Applicable Sub-tasks
A. Inherent	
1. Authorized personnel strength by type	CC, RE, R, T
2. Authorized equipment strength by type	CC, RE, R, RPS, T
3. Maintenance level	CC, RE, R
4. Forecast horizon (area of interest)	CC, RE, R, RPS, T
5. Fraction productive manhours by personnel type per time period	CC, RE, R, RPS
6. Supply level: PLL or ASL	RPS
7. Site terrain requirements	T
B. State Dependent	
8. Entity location	CC, RE, R, RPS, T
9. Location of forward deployed elements	CC, RE, R, T
10. Entity collection point location(s)	CC, RE, R, T
11. Pointer to subordinate maintenance entities	CC, T
12. Pointer to superior maintenance entities	CC,T
13. Pointer to supporting maintenance entities	CC, RE, R, T
14. Pointer to supporting parts suppliers	CC, RPS, T
15. List of supported combat entities	CC, RE, R, RPS, T
16. Locations of supported combat entities	CC, RE, R, RPS, T
17. Current personnel strength by type	CC, RE, R, T
18. Available personnel strength by type	CC, RE, R, T
19. Current equipment strength by type	CC, RE, R, RPS, T
20. Available equipment strength by type	CC, RE, R, RPS, T
21. Current MTC by type	CC, RE, R, T
22. Support priorities by combat entities	CC, RE, R, RPS
23. Support priorities by equipment type	CC, RE, R, RPS, T
24. Maintenance report requirements	CC, RE, R, RPS
25. Fuel status	CC, RE, R, RPS, T

LEGEND:
Command and control - CC   Repair - R
Repair parts supply - RPS   Tactical - T
Recovery and evacuation - RE

Table I

General Maintenance Entity Attributes (cont'd)

Attributes	Applicable Sub-tasks
26. Recovery mission list (workload) mission type and status	CC, RE
27. MSR designation	CC, RE, R, RPS, T
28. Recovery compatibility list - type vehicle for equipment type	CC, RE
29. Repair compatibility list - type personnel for equipment type	CC, R
30. Repair mission list (workload) - repair type, status, parts needs	R
31. MCP mission list (workload)	R
32. Authorized stockage by item - repair parts, DX items, ORF items	RPS
33. Current stockage by item	RPS
34. Reorder level by item	RPS
35. Supply mission list (workload) - due ins, due outs, ORF repair status	CC, RPS
36. Distance from FLOT	T
37. Distance from supported unit trains	T
38. Site breakdown time	T
39. Site set up time	T
40. Lowest acceptable road trafficability	T
41. Maximum vehicle weight classification	T
42. Maximum vehicle width	T
43. Maximum convoy speed	T
44. Maximum convoy length	T
45. Fraction personnel at security posts	T
46. Tactical report requirements	T

LEGEND:
Command and control - CC   Repair - R
Repair parts supply - RPS   Tactical - T
Recovery and evacuation - RE

these relationships is well defined but is often situationally modified by specific exceptions or inclusions dictated by the task organizing command and control element.

In general within a division company organizational maintenance teams are either organic or attached; battalion organizational maintenance platoons are organic; DS

	COMMAND			SUPPORT
A maintenance element with a relationship of-	Organic	Attached	OPCON	Direct Support (DS)
Is under command and control of-	Parent unit	Supported unit	Supported unit, less administration and logistics	Parent unit
Establishes liaison and communication with-	Parent to subordinate unit	Supported to supporting unit	Supporting to supported unit	Supporting to supported unit
May be task organized by-	Parent unit	Supported unit	Supported unit	Supporting or parent unit
Relationship/assignment normally given-	Task specific assignments	Further attached or DS to subordinate supported units	Further OPCON to other maint units or DS to sub spted units	Support of units by task specific or area basis
Responds to support requests from-	Parent unit	Supported unit	Supported unit	Supported unit and parent unit
Work priority established by-	Parent unit	Supported unit	Supported unit	Parent unit with input from supported unit
Spare work effort available to-	Parent unit	Supported unit	Supported unit	Parent unit
Request for additional support forwarded through-	Parent unit	Supported unit	Supported unit	Parent unit

Figure 2.3 Maintenance Command and Support Relationships.

maintenance companies are in direct support of supported units; DS MSTs are in direct support of supported units and may be OPCON to them; and Corps DS elements are either attached or OPCON to divisional maintenance units while in direct support of division.

Another relationship essential to successful execution of maintenance support, particularly under the fix forward operational concept, is close liaison or coordination among all adjacent maintenance elements of a specific hierarchical level. This coordination often involves duplicate submission of reports in order to expedite execution.

The structure of maintenance command and control is similar to that of maneuver and combat command and control. Each maintenance element has either a staff or several supervisory personnel responsible to the commander for providing reports, issuing orders, and monitoring order execution. These personnel operate from a command post and generally have some communications system available. Figure 2.4 is a pictorial depiction of a division maintenance command and control structure and interconnectivity.

Organizational maintenance information flows through maneuver command and control channels via the unit's administrative/logistic (A/L) net rather than the command net. From brigade level this information also flows directly to DISCOM. Conversely, DS maintenance information flows along maintenance unit command and control channels to the appropriate level via unit command nets.

D. DEMANDS UPON MAINTENANCE SUPPORT

1. Definition of Maintenance Demand

A maintenance demand is any externally produced or generated requirement for maintenance support action. The requirement is one of several forms - repair parts need, repair need, recovery or evacuation need, request for additional support, or any combination of these.

Once generated a demand must be processed successively through the hierarchical levels of support until it is either satisfied or cancelled. Satisfaction occurs when the requirement is fulfilled or successfully accomplished. Cancellation occurs when the owning or requesting entity

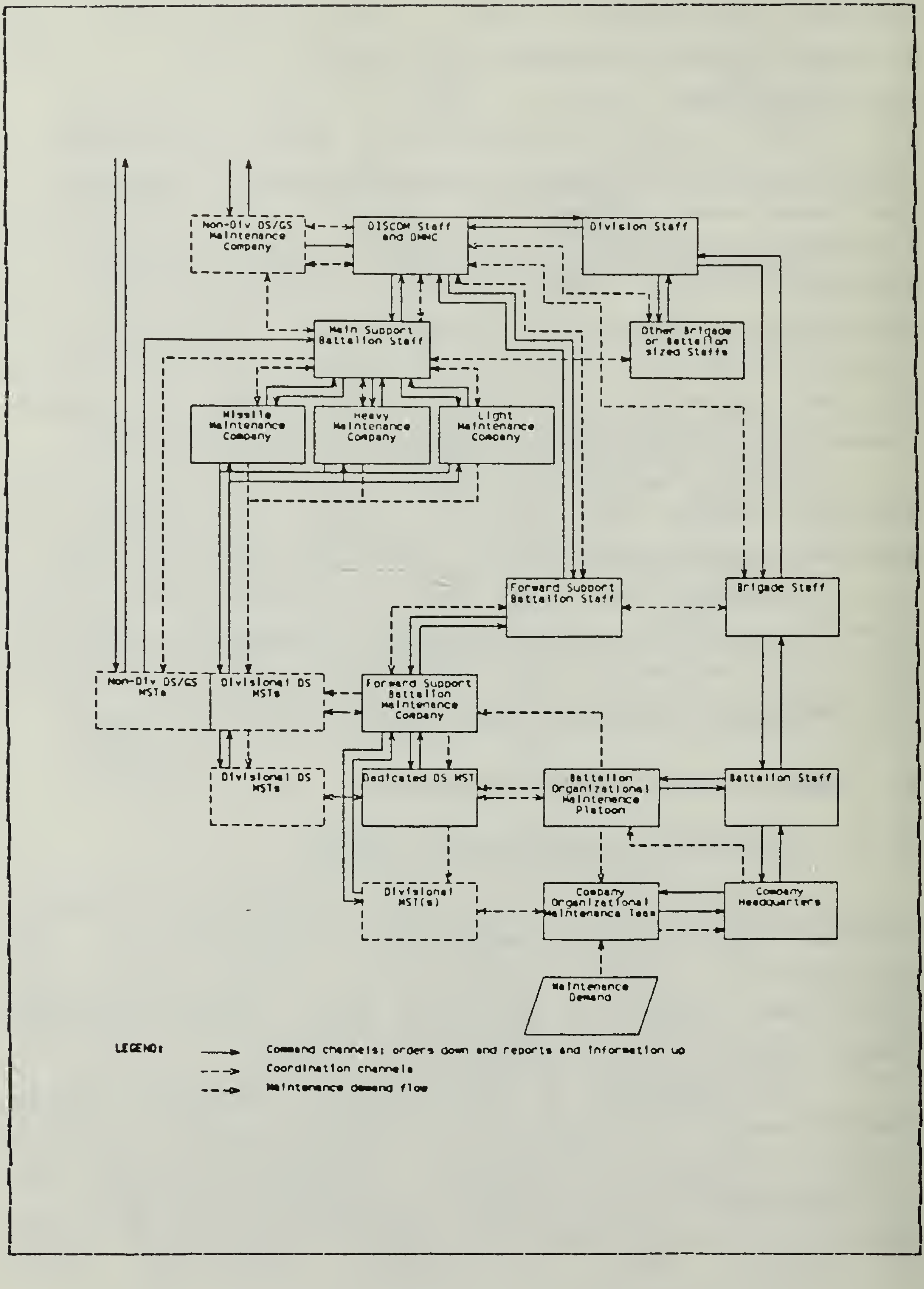

Non-Div DS/GS Maintenance Company
DISCOM Staff and DMMC
Division Staff
Main Support Battalion Staff
Other Brigade or Battalion sized Staffs
Missile Maintenance Company
Heavy Maintenance Company
Light Maintenance Company
Forward Support Battalion Staff
Brigade Staff
Non-Div DS/GS MSTs
Divisional DS MSTs
Forward Support Battalion Maintenance Company
Divisional DS MSTs
Dedicated DS MST
Battalion Organizational Maintenance Platoon
Battalion Staff
Divisional MST(s)
Company Organizational Maintenance Team
Company Headquarters
Maintenance Demand
LEGEND:
Command channels: orders down and reports and information up
Coordination channels
Maintenance demand flow

Figure 2.4 Maintenance C^2 Interconnectivity.

cancels the requirement or the final processing maintenance entity denies additional support or declares an item uneconomically repairable. A declaration of uneconomically repairable causes a demand to be placed upon the Class VII supply system to replace the item.

2. Generation of Maintenance Demands

Maintenance demands are either reports of unserviceable equipment, repair parts needs, or recovery needs or requests for repair, recovery, repair parts, or additional support. Either type of demand is first processed by the receiving maintenance entity and is either satisfied or cancelled at that level or sent as a request to a higher supporting maintenance entity for processing.

Reports are generated as a result of an equipment failure, an equipment combat damage, a combat loss of repair parts, repair parts stockage reaching a reorder point, or an equipment becoming terrain stuck. Reports require only an internal processing by the receiving maintenance entity but need not require action. However, if this first maintenance entity is unable to satisfy or cancel the requirement, a request for support is generated and sent to the next higher supporting maintenance entity.

Requests are generated by a maintenance entity in response to an inability to satisfy, cancel, or process a maintenance demand. All requests are sent to the next higher supporting maintenance entity and require action to be taken by that supporting maintenance entity.

3. General Attributes of Maintenance Demands

As maintenance demands initiate the maintenance support process, each must possess general attributes required for maintenance support planning, execution, or decision making. These attributes are either inherent (fixed) to the demand or state dependent (variable). These general attributes are listed in Table II. Each maintenance demand possesses a subset of these general attributes.

In summary, the organization , structure, and functions of the maintenance support system in the U.S. Army's Division 86 force structure were discussed to provide the necessary background information for purposes of conceptualizing a model of the system. The next chapter discusses several modelling issues as a prelude to formulation of a maintenance support model structure.

TABLE II

General Maintenance Demand Attributes

A. Inherent

1. Generating entity
2. Entity owning equipment or repair part
3. Weapon system type
4. Equipment repair code (ERC)
5. Clock time of occurrence
6. Repair part code(s)
7. Quantity of repair parts
8. Demand type- report or request
9. Request type - recovery, repair, repair part, additional support
10. Repairability code
11. Repair level code
12. Conditional mean time to repair by personnel type
13. Number of mechanics by personnel type

B. State Dependent

1. Location of equipment or parts stockage
2. Salvage code
3. Conditional repair time in clock hours by personnel type
4. Expected total repair time in clock hours
5. Expected total recovery time in clock hours
6. Parts acquisition time

III. MODELLING ISSUES

A. INTRODUCTION

In this chapter, several modelling issues are examined as preliminary information towards determining the structure of the initial stage maintenance support model in support of the Airland Research effort. Hughes states that "the pedestrian process of pinning down the study objective, the decision criteria, the measures of effectiveness, the availability and quality of data, and the scenario will go a long way toward determining the structure of the model" [Ref. 6: p. 18].

In the context of determining the maintenance support model structure, overviews of the maintenance modelling methodology of two existing division level or higher combat models are presented and the following issues examined:

1. Possible objectives for modelling maintenance support in the Airland Research Model.
2. The required resolution of the maintenance support model.
3. Maintenance support data sources.

B. TWO EXISTING MODEL METHODOLOGIES

1. Force Combat Evaluation Model (FORCEM)

FORCEM is a deterministic, theater-level combat model. Its representation of maintenance support is deterministic using expected value type data. The decision process of repair versus recovery versus abandonment is explicitly modelled with user input static decision criteria. However, the execution processes are implicitly modelled [Ref. 7: pp. 6-23].

The following maintenance functions are modelled: battlefield recovery and evacuation which includes recovery time forecasting, self and like recovery, recovery asset allocation, and recovery execution; repair which includes repair asset allocation, demand overflow, and repair execution; and repair parts supply which includes operational readiness float (ORF) and repair parts issues.

The model represents equipment by general vehicle type classes and maintenance personnel as one personnel type capable of repairing any type of demand. Demands are of two types - DS or GS level repair. Repair parts are represented simply as tons of parts and each general vehicle type require a predetermined quantity in tons of repair parts.

Recovery and evacuation routines are called once for every model cycle to collect casualties and generate maintenance queues. Then the maintenance routines are called once every 24 hours of simulation time.

This model does not portray prioritization of workloads nor does it allow for maintenance asset attrition any place other than at base locations - equipment pools.

2. Army Unit Readiness/Sustainability Assessor (AURA)

AURA is a Monte Carlo discrete event simulation model which analyzes the interrelations among available resources and the capability of the units to generate weapon system missions in a dynamic wartime environment [Ref. 8: pp. 13-93].

Maintenance support is modelled explicitly in AURA. The model allows the user to specify up to 25 groupings of maintenance assets into shops and any number of user defined vehicle maintenance tasks. Also, each task can be defined as either a one-step procedure, multi-step network of subtasks, or a sequence of multi-step task networks.

The maintenance functions represented are unscheduled maintenance, pre-mission maintenance, battle damage repair, deferred maintenance, cannibalization, repair parts supply with a user defined inventory list, and subcomponent repair.

The model explicitly represents the maintenance decision processes. The repair versus evacuate decision process uses a user defined static decision criteria. The model forecasts return of inoperable equipment and generation of mission needs of vehicle types for use in establishing maintenance priorities for workload management.

This model also allows simulation of attacks upon rear areas for purposes of examining the effects upon maintenance support capabilities.

Overall this model is rather robust as its design allows great flexibility in user definitions of equipment inventories, repair parts inventories, maintenance skills represented, combat force structures, and maintenance and supply doctrines.

C. OBJECTIVES OF MODELLING COMBAT MAINTENANCE SUPPORT

The ultimate objective of the Airland Research Model is examination of the U.S. Army's AirLand Battle Doctrine and the complex operational decisions of battle management. Any maintenance support model designed as a part of this model must be structured to meet this objective. Thus, the maintenance support model must primarily provide a manifestation of the impact of maintenance support upon the combat operations of interest.

Any study objective relating to this impact of maintenance support upon combat operations is relevant to the Airland Research Model effort. Several of these possible objectives are listed below:

1. Determination of the combat value of maintenance support entities.
2. Examination of the interrelationship between the maintenance, supply, and transportation support systems and their combined impact upon combat operations.
3. Investigation of the effects of rear area interdiction upon maintenance support entities and the resultant impact upon the maintenance support system.
4. Evaluation of specific maintenance management policies.
5. Evaluation of the impact of specific combat tactics, doctrine, force structures, or equipment modernizations upon a current or proposed maintenance support system.
6. Determination of the characteristics of the maintenance support demand function at any specific hierarchical level under "equivalent" scenarios and mission conditions.

Obviously, several of these objectives can be met simultaneously. However, during the initial stages of research on the Airland Research Model, the focus is upon determining the combat value of maintenance support entities.

D. ALTERNATIVE METHODS FOR MAINTENANCE SUPPORT REPRESENTATION

With the objectives of the maintenance support model developed, the next issue is that of how to represent the maintenance support processes of returning weapon systems to combat. Two alternative methods of representation are:

1. An explicit model of the sequential event processing of maintenance requirements, and

2. An implicit model of the processing of maintenance requirements utilizing a "black box" of prioritized stochastic processes which characterize the maintenance processes and generates returns to combat.

Historically, combat models have been developed in stages. The first stages attempt to capture the real world functions, parameters, and heuristics through development of explicit, sequential or simultaneous, functional process representations. These first steps provide the tools for the study of each of the functional processes and the empirical evidence required to characterize the functions by stochastic processes. Thus, the later stages of combat model development attempt to capture the real world processes through development of implicit models of the functions using characteristic stochastic processes.

The method of explicitly representing the sequential events of a process is relatively less difficult to develop than the method of an implicit representation. The implicit method requires considerable effort and time in studying the real world processes of interest and explicit models of the processes in to gain insight into identifying the stochastic processes involved and developing a data base of process parameters.

The identification of the significant stochastic processes and their parameters for combat maintenance support has not received much effort from the U.S. Army modelling community up to now. Many explicit models of maintenance support have been developed, but few have modelled maintenance support under combat conditions in tandem with a combat model.

In this context, the method of representation of maintenance support in the initial stage model in support of the Airland Research effort must be an explicit, sequential event method.

E. RESOLUTION OF MAINTENANCE SUPPORT

A major issue in designing the maintenance support model is determination of the level of resolution or detail of the model. Should the lowest entity represented be battalion, company, section, team, or system crew? If the level of detail is very high, the modeller must be prepared to accept long model run times. Alternatively, if the level of detail is very low, the modeller must be prepared for a loss of variable interrelationship effects.

1. Considerations in Determining a Level of Resolution

The selection of an explicit method of representing maintenance support requires detailed sequential process modelling. However, the level of resolution must be based upon several other factors discussed below.

One consideration is the complexity of the process being modelled. The maintenance support function is characterized by a hierarchical network of multistaged, prioritized queues. The dynamic nature of the prioritization of these queues creates frequent preemption within the queues and an added difficulty in understanding the complex functioning of the queues. A logical initial resolution level in this context would be the lowest maintenance entity with queues. This entity is the company level maintenance team.

A selection of a higher level of resolution would be more desirable in order to reduce the numbers of entities represented and data storage requirements if a means for aggregating individual personnel type or team maintenance function parameters was available. However, methods of aggregating the functioning of the diverse personnel skills of maintenance support have not been fully developed to date. Thus, a higher level of resolution than company level maintenance team is initially infeasible.

Another consideration in determining the level of resolution is the availability of combat maintenance demand parameters. Currently, almost no combat data on the combat damage of weapon systems exist. This lack of combat damage data leads to a need to develop a detailed model to provide a reservoir of raw pseudo-data and benchmarks as suggested by Hughes [Ref. 6: p. 20].

2. Proposed Level of Resolution

Due to the complexity of the maintenance support queueing network and the lack of aggregated personnel type repair function parameter data, the level of resolution selected for the initial stage maintenance support model is the company level maintenance team. The individual personnel types can be represented as attributes of the entities for the purpose of using repair function data by individual personnel type. Subsequent research utilizing the initial stage maintenance support model should provide data for aggregation to a higher level of resolution.

It is also proposed that maintenance demands have an initial level of resolution of individual weapon systems by type despite the scarcity of combat damage data. This level of resolution allows examination of the non-homogeneous effects of different repair tasks and weapon system types. However, the number of type repair tasks by weapon system type is to be limited to a representative set of tasks for each level of maintenance support chosen by expert judgment. Each task and the repair part types needed must match specific personnel types.

F. DATA SOURCES

Several possible data sources for the primary maintenance support data needs are identified and briefly discussed in this section. In many cases suitable data for all maintenance simulation needs does not exist. However, proposed methods of obtaining or producing the data are discussed.

An initial starting point in a search for any of the required maintenance data is the Maintenance Task Demand (MTD) file maintained at the U.S. Army Logistics Center. This file was developed and designed by the BDM Services Company for the U.S. Army Logistics Center as an automated data system for maintenance oriented modelling and simulation needs at the center and its associated schools [Ref. 9]. Some of the key data elements included in the file design are:

1. End item identification and information.
2. Scenario codes.
3. Mean time between failure data.
4. Mean time to repair data.
5. Manpower Authorization Criteria (MACRIT) data.
6. Maintenance Allocation Chart (MAC) data.
7. Equipment usage data.
8. Maintenance tasks requirements.
9. Repair parts requirements.
10. Personnel type requirements.

A major disadvantage to the use of the MTD file as a data source is that only five end items are currently maintained in the file.

Other possible data sources by key data types are discussed below.

1. Equipment Combat Damage Distribution Data

Currently, almost no combat damage distributions by equipment type exist in the U.S. Army. This is due to the general lack of reliable combat data and the relative newness of the U.S. Army's current equipment. However, a study was conducted using combat data from the 1973 Middle East War by the U.S. Army Ordnance and Chemical Center and School to generate a combat damage distribution of the M60A1 tank.

This study produced the Combat Damage Assessment Model (CODAM) [Ref. 10]. The study group utilized actual hit locations and perforations from 200 tanks damaged during the war to compile a distribution of hits model and a penetration model. The study group then utilized ballistic phenomenological data to construct damage cones for each perpendicular shot line. The compiled lists of shot lines and damage cones were then given to work groups of senior enlisted and warrant maintenance personnel as expert judges to determine the extent of probable damage, level of maintenance needed, manpower requirements by personnel type, repair parts needs, and estimated repair times. These work group worksheets were then compiled into damage distributions for each shot line.

The major drawback to the CODAM study is its limitation to a single weapon system under a single scenario. However, extensions of the study are feasible utilizing vulnerability and shot line models from the U.S. Army Ballistics Research Laboratory (BRL) and hit probabilities from Army Materiel Systems Analysis Activity (AMSAA) to develop a computer based model for generation of combat damage distributions.

An exploratory use of this methodology has been accomplished in the generation of combat damage demands in a Manpower Authorization Criteria (MACRIT) study [Ref. 11: pp. 3-17 - 3-24]. This study utilized Sustainability Predictions for Army Spare Component Requirements for Combat (SPARC) generated by BRL and AMSAA which yielded sets of shot lines and their probabilities of occurrence and a list of components damaged.

2. Equipment Failure Distribution Data

In addition to the MTD file, several other possible sources of equipment failure distributions exist dependent upon the form of the data required. In most cases the data is mean time between failures (MTBF) in either distances or time. Some of these possible sources are:

1. Unit equipment maintenance historical records.
2. Selected end item data collected by the Army Materiel Command (AMC).
3. Equipment maintenance historical records of equipment in the National Training Center (NTC) equipment pools.

A major drawback to all of these sources is that the data collected reflects a peacetime usage rather than a wartime usage. In this context, the NTC equipment records more closely approximate the war time environment since the equipment is only used for force-on-force war game exercises. Also, since the data collection methods of these sources was not originally intended for simulation uses, data quality problems could be substantial.

3. Equipment Repair Time Data

Possible sources of equipment repair time data in addition to the MTD file are similar to those for equipment failure distribution data. This repair time data is most commonly obtained as mean time to repair (MTTR) in manhours by personnel type. Two possible sources are:

1. U.S. Army Maintenance Allocation Chart (MAC) technical manuals.
2. Standard Army Maintenance System (SAMS) records.

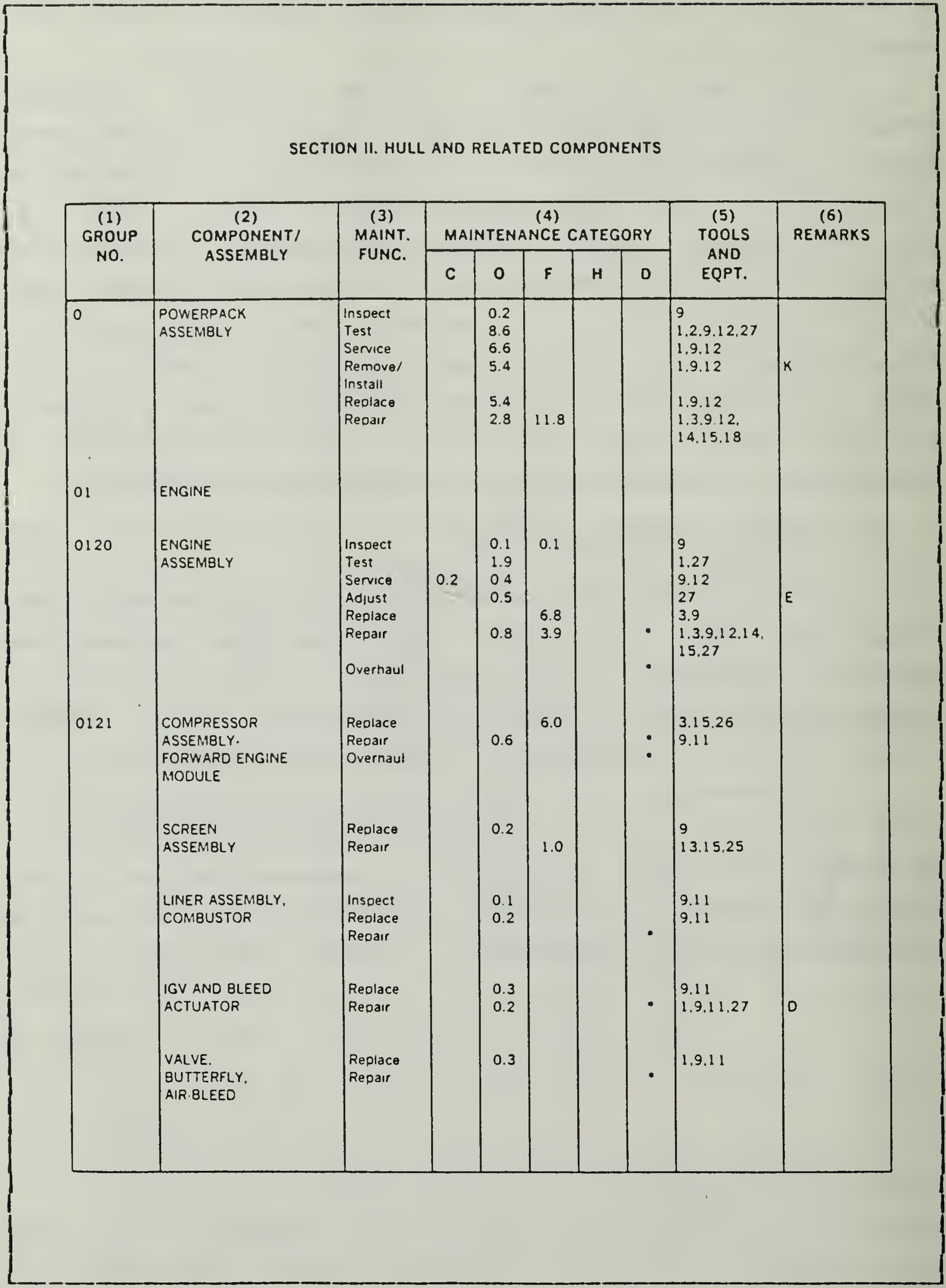
Again both sources reflect a peacetime environment where most equipment is repaired in fixed or semi-fixed maintenance facilities and not in the field. Additionally, the SAMS data is limited to DS or higher type repairs and is maintained at individual maintenance company or battalion levels.

For lack of a better source, the MAC technical manuals are the most readily available and require the least amount of data compilation. A MAC technical manual is published for each weapon system in the U.S. Army. It provides expected repair times in manhours at each maintenance level for detailed equipment subcomponent repair tasks which are identifiable to personnel types. An example of the information in a MAC is shown in figure 12 [Ref. 12: p. 2-1]. Additionally, MACs were used in the previously mentioned MACRIT study and matched SPARC component lists to maintenance tasks for generation of maintenance demands.

4. Other Maintenance Data

Other maintenance data required such as percentage daily work hours by personnel type, movement caused work capability changes, and maintenance time criteria by personnel type are not readily available. They require expert heuristic judgment as a basis for development.

In summary, the issues of the maintenance model's study objectives, level of resolution, and data sources were discussed to provide foundational information for structuring the model. An actual formulated structure of the maintenance model is presented in the next chapter.



SECTION II. HULL AND RELATED COMPONENTS

(1) GROUP NO.	(2) COMPONENT/ ASSEMBLY	(3) MAINT. FUNC.	(4) MAINTENANCE CATEGORY					(5) TOOLS AND EQPT.	(6) REMARKS
			C	O	F	H	D		
0	POWERPACK ASSEMBLY	Inspect		0.2				9	
		Test		8.6				1,2,9,12,27	
		Service		6.6				1,9,12	
		Remove/ Install		5.4				1,9,12	K
		Replace		5.4				1,9,12	
		Repair		2.8	11.8			1,3,9,12, 14,15,18	
01	ENGINE								
0120	ENGINE ASSEMBLY	Inspect		0.1	0.1			9	
		Test		1.9				1,27	
		Service	0.2	0 4				9,12	
		Adjust		0.5				27	E
		Replace			6.8			3,9	
		Repair		0.8	3.9		•	1,3,9,12,14, 15,27	
		Overhaul					•		
0121	COMPRESSOR ASSEMBLY- FORWARD ENGINE MODULE	Replace			6.0			3,15,26	
		Repair		0.6			•	9,11	
		Overhaul					•		
	SCREEN ASSEMBLY	Replace		0.2				9	
		Repair			1.0			13,15,25	
	LINER ASSEMBLY, COMBUSTOR	Inspect		0.1				9,11	
		Replace		0.2				9,11	
		Repair					•		
	IGV AND BLEED ACTUATOR	Replace		0.3				9,11	
		Repair		0.2			•	1,9,11,27	D
	VALVE, BUTTERFLY, AIR-BLEED	Replace		0.3				1,9,11	
		Repair					•		

Figure 3.1 Maintenance Allocation Chart Information.

IV. MAINTENANCE SUPPORT MODULE DESIGN

A. INTRODUCTION

This chapter presents a general concept for the design of the maintenance support model for the Airland Research Model. The general processes uniquely involved in maintenance support are identified, described, and categorized as either a planning or an execution process. A generalized structure of the model is proposed by identifying and describing the model components and their interrelationships. Also, some specific planning processes which are developed into algorithms in this thesis are discussed in detail.

B. MAINTENANCE SUPPORT GENERAL PROCESSES

1. Types of Processes

Every maintenance support process is classified as either a planning or an execution process. The planning processes synthesize less complete state information into orders or actions which are input to the execution processes as guidance. The execution processes subsequently carry out assigned tasks using the most current and complete state information within the guidelines established by the planning processes. If the current state information indicates conditions which violate the planning guidelines, the execution processes provide feedback to the planning processes for updating guidance. The result is that the planning and execution processes interact iteratively until a specific task or mission is accomplished or cancelled. A depiction of this interaction is shown in figure 4.1.

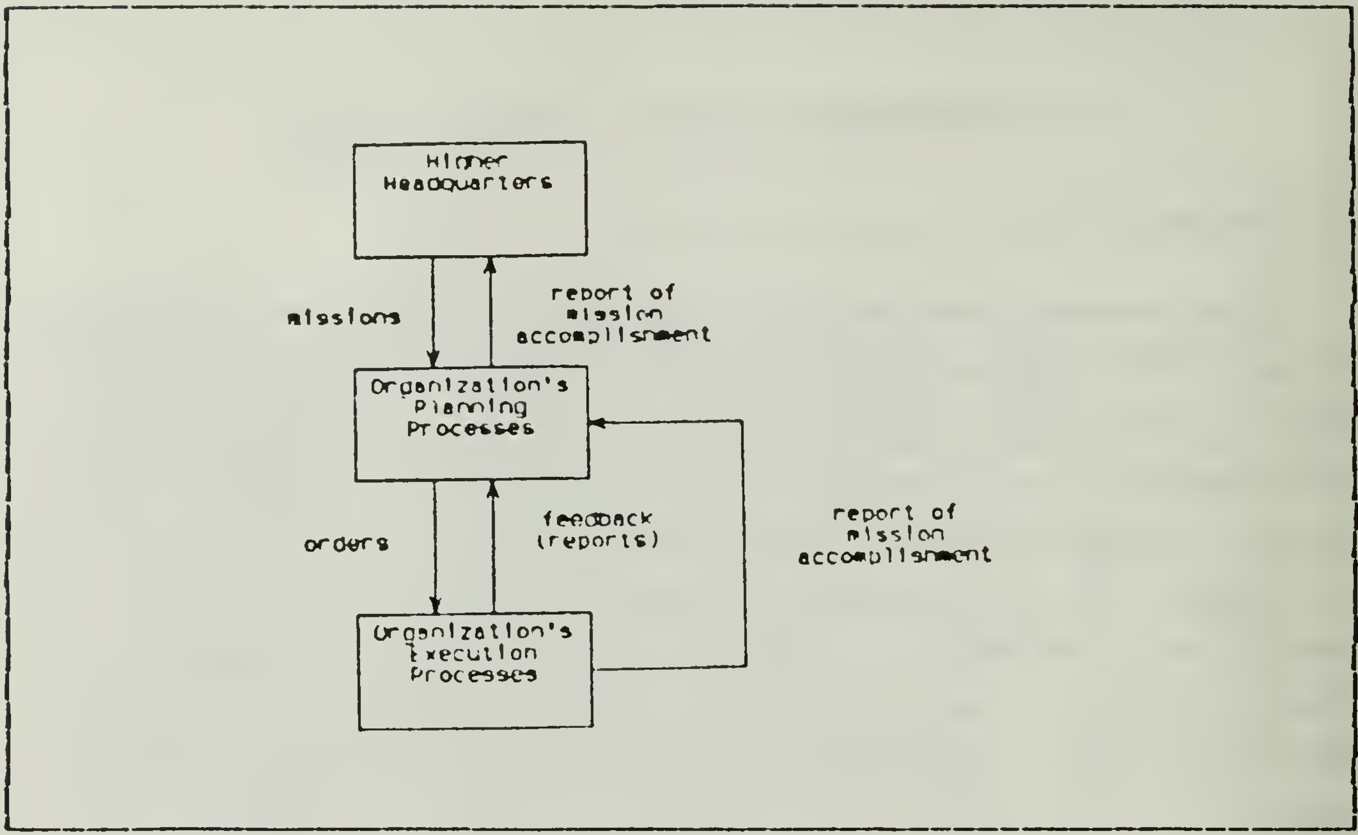

Higher Headquarters
missions
report of mission accomplishment
Organization's Planning Processes
orders
feedback (reports)
report of mission accomplishment
Organization's Execution Processes

Figure 4.1 Planning and Execution Interaction.

Since most maintenance information is state dependent, decisions are made in both planning and execution processes. The maintenance information needed for these decisions is updated by reports from external sources or from internal feedback. However, in most cases the primary difference between similar decisions within a planning and an execution process is that although the execution process decision is made with identical logic as the planning decision, the execution process decision uses more current and detailed information.

Planning processes essentially make decisions by forecasting the future state of maintenance support and making feasibility checks against established guidelines. The forecast horizon used is identical to the magnitude of the supported unit's area of interest time. These times are 12 hours for battalion level, 24 hours for brigade level, and 72 hours for division level [Ref. 13: p. B-4]. The forecasts are either heuristic or utilize the physical subprocesses of the execution processes.

Execution processes consist of two type subprocesses: decision and physical. The decision subprocesses make feasibility checks on current state information as a decision basis without forecasting future states. The physical subprocesses perform assigned physical tasks such as repairing an item of equipment or recovering an item of equipment.

2. Key Maintenance Support Processes

a. Planning Processes

All the planning processes discussed in this chapter are short term in nature, since long term maintenance support planning processes have planning horizons which exceed the proposed battle lengths of the Airland Research Model.

There are six basic maintenance support planning processes which should be modelled. The six processes are:

1. Triage.
2. Workload prioritization.
3. Maintenance time criteria update.
4. Work capability change forecast due to forecasted movement.
5. Allocation of maintenance entities for support.
6. Allocation of maintenance support teams (MSTs) for temporary forward deployment.

Each of these processes is discussed below.

Triage is the first planning process to occur after receipt of a maintenance demand. The triage process decides whether to satisfy or cancel the demand at the receiving maintenance entity or to pass the demand to the next higher supporting maintenance entity. This decision is based upon the priority assigned to the demand, and the receiving maintenance entity's workload and the maintenance time criteria (MTC).

Workload prioritization is an ongoing process which uses the current state information as a basis for assignment of maintenance priorities. Both unit and equipment priorities are established for each maintenance hierarchical level by the primary maintenance entity at that level. Unit priorities are identical to the current tactical unit priorities established by the supported combat force commander. Equipment priorities are based upon the current pooled operational readiness rate of the equipment type at the hierarchical level concerned; whether the equipment type is the unit's primary weapon system; and the equipment priorities established by the next higher hierarchical level. Normally, the maintenance demand queue of a maintenance entity is prioritized by nesting the equipment prioritization scheme within the unit prioritization scheme. This process is initiated by a change in the supported hierarchy's mission posture or by the nth demand received at a maintenance entity since the last priority update.

Maintenance time criteria (MTC) determination is the process of updating the initially established MTCs. Each operations order/plan generates an initial set of MTCs for the maintenance entities involved based upon the supported hierarchy's mission posture. Each entity's MTC requires reevaluation whenever one of the three following events occur: the supported hierarchy's mission posture changes; the receipt of the nth demand for a personnel type at the maintenance entity; or displacement preparation(completion) begins(ends).

The work capability change forecast process is the process of using the updated forecasted displacement times of the maintenance entities for the current combat mission being executed to generate updated scheduled work force capability changes for execution of the planned movement. These scheduled changes are subsequently used for updating the maintenance time criteria (MTC). Each operations order/plan generates a forecast of each force's trains displacements. This forecast is made by the supported force commander with input from the various logistical elements of the force's trains. These four primary factors influence the need for displacement of a unit's trains:

1. The trains location be no closer than a minimum distance from the enemy.
2. The trains location be no farther than a maximum support distance in time from the units being supported.
3. The trains location be no farther than a maximum communications distance from the next higher level of support.
4. The existence of a more suitable trains location if any of the three factors above are violated. The new location must meet the criteria stated above as well as being suitable terrain for logistical operations.

For each change in the forecasted movement time, this process generates the times at which the work force capability of the maintenance entity is degraded (for pre-movement preparation) and improved (for after movement set-up stage completion). These times are at preset intervals from the forecasted movement and arrival times.

Allocation of maintenance entities for support is normally done only once within the initial operations planning sequence. Organic maintenance entities within the division have well established support assignments which change only upon major combat losses by maintenance entities. In such a case of combat loss, support assignments are normally reallocated by hierarchical level by combining the remaining maintenance assets of a damaged entity with another entity which then assumes the support mission for both the damaged entity and itself. Maintenance entities provided from Corps assets to the division are normally integrated into the division level maintenance effort in the Division Support Area (DSA).

Allocation of maintenance teams or maintenance support teams for forward deployment in a temporary support role is an ongoing process. Deployment of these teams is based upon the simultaneous existence of the following factors:

1. The supported maintenance entity has a backlog of demands which exceeds its capability within current maintenance time criteria (MTC) but several of the backlog demands could be repaired within the maintenance time criteria (MTC) with additional personnel and equipment and require no waiting for parts, and
2. The supporting maintenance entity has an excess of available capability or the recovery backlog at the supported maintenance entity exceeds a threshold.

If these simultaneous conditions are met, a maintenance team(s) is deployed forward until either the identified backlog demands are completed or the supporting maintenance entity's workload exceeds its threshold and the backlog demands of the supporting entity with no parts shortage have higher priorities than the demands being repaired by the deployed team.

b. Execution Processes

There are several execution processes unique to the maintenance support model. The key execution processes required for modelling maintenance are:

1. The repair process.

2. The repair parts supply process.
3. The recovery process.
4. The maintenance demand generation process.
5. The reports process.
6. The return (return of repaired items to owning units) process.
7. The maintenance support team (MST) deployment process.

Each of these execution processes is discussed below.

The repair process allocates available (organic, attached, and OPCON) maintenance assets - personnel and equipment - to satisfy the maintenance demands on a maintenance entity's waiting repair list which is updated by the triage planning process. These demands include equipment repair, conduct of controlled exchange, and conduct of cannibalization. These demands are processed according to the current maintenance priorities. For those demands which are repairs, the process sends a report to the repair parts supply process to update the stockage list. The process matches the appropriate type(s) of personnel and equipment to the demand's equipment repair code and determines the completion time for the demand. Then the process places the demand on the waiting pickup list and removes it from the waiting repair list. The return process is then sent a report of completion as well as the maintenance demand generation process for scheduling of the next failure for the item.

The repair parts supply process issues, requisitions, and receives repair parts. A report received from the repair process causes the repair parts supply process to decrement the stockage appropriately. The process then checks the updated stockage level to determine if the reorder point has been reached. If the reorder point has been reached, the process generates a requisition for the quantity of parts to bring the stockage to full authorization and sends it to the supporting repair parts supplier. Also, this process generates a requisition for the repair parts needed for each demand placed on the waiting parts list by the triage process. The receipt action of this process is initiated by a report of receipt of a requisition. The process then checks the requisition to determine whether it was a stockage (due-in) or demand (due-out) request. If the request was for stockage, the process updates the stockage level and removes the requisitions from the due-in list. If the request was a demand, the process changes the waiting parts attribute of the highest priority maintenance demand requiring only that part, tags the part to the demand, and if all parts needed by the demand are on hand, places the demand on the waiting repair list.

The recovery process allocates available (organic, attached, and OPCON) recovery assets to satisfy the maintenance demands on a maintenance entity's waiting recovery list. The demands are processed according to the current maintenance priorities. The process determines the location to which the item is to be recovered, and the completion time for the recovery operation. This time includes pre-recovery, recovery, and post recovery times. The maintenance demand is then removed from the waiting recovery list and placed on the waiting return list of the maintenance entity. The process also generates a recovery request type maintenance demand to the supporting maintenance entity with duplicate information of the original demand. This recovery request demand is then placed on the supporting maintenance entity's waiting triage list.

The maintenance demand generation process has two parts: one which generates equipment failures and another which generates combat damage based upon input from a combat attrition model. The equipment failure part utilizes the failure time distributions and failure type distributions of each type of equipment and through use of Monte Carlo methods initially schedules a failure time and an equipment repair code (ERC) for each item of equipment. These "scheduled" failure times with ERC are regenerated after each repair completion. When a scheduled failure time occurs a report of the equipment failure is sent to the supporting maintenance entity and the owning unit's equipment status is updated. Combat damage generation is initiated by a report from the combat attrition model identifying the specific items of equipment and the owning units. The process uses the equipment type combat damage distributions and Monte Carlo methods to determine an equipment repair code for each item. A report for each item is then sent to the appropriate supporting maintenance entity and the owning unit for equipment status update. Also, for each item combat damaged, the process resets the item's scheduled failure time to zero.

The reports process sends the required reports from each maintenance entity to its appropriate report headquarters at the prescribed report interval or upon violation of established planning thresholds. These reports are used by higher level maintenance entities for planning purposes. The key reports submitted are the unit equipment status, unit workload in both recovery and repair, and the current repair parts stockage levels. These reports are submitted through command channels and through maintenance channels at intervals established by higher headquarters.

The return process returns a repaired item to the owning unit when report of repair completion is received from the repair process. The process determines the time to return the item - notification of owning unit time and actual return time - and schedules the update of the owning unit's equipment status. The process additionally removes the maintenance demand from all waiting return lists.

The MST deployment process removes the appropriate quantity of personnel and equipment from the supporting maintenance entity's available assets list and places them on this entity's deployed list. The process then schedules the travel to the supported maintenance entity by sending a transportation notice to the transportation model. The process also places the designated quantity of personnel and equipment on the supported maintenance entity's asset list with a pending arrival code. A report of movement completion from the transportation model changes this pending arrival code to an OPCON code. If the MST fails to finish the movement for any reason, the report of this occurrence results in removal of the MST from the supported maintenance entity's asset list and generates a new call to the allocation of maintenance assets for temporary forward deployment process for a new planning decision.

C. GENERAL STRUCTURE OF THE MAINTENANCE SUPPORT MODULE

1. Components of the Module

The maintenance support model must consist of several maintenance unique components which are sequences of either planning, execution, or both type processes. Each of the components has a stable sequence of processes which interacts with other components of the maintenance model or external models of the combat model.

There are seven principal components of maintenance support which require modelling. The seven components are:

1. Maintenance Demand Generation.
2. Maintenance Demand Scheduling.
3. Maintenance Demand Execution.
4. Workload Prioritization.
5. Maintenance Time Criteria Determination.
6. Work Capability Change Forecast.

7. Reporting.

Each of these components and their sequence is discussed below.

a. Maintenance Demand Generation Component

The Maintenance Demand Generation component begins with the combat model initialization, attrition results, completion of a demand's repair, or occurrence of a scheduled failure time as input to the maintenance demand generation process. The maintenance demand generation process uses the input and either schedules item failure(s) or generates a maintenance demand to the appropriate maintenance entity for input to the maintenance demand scheduling component. This sequence is shown in figure 4.2.

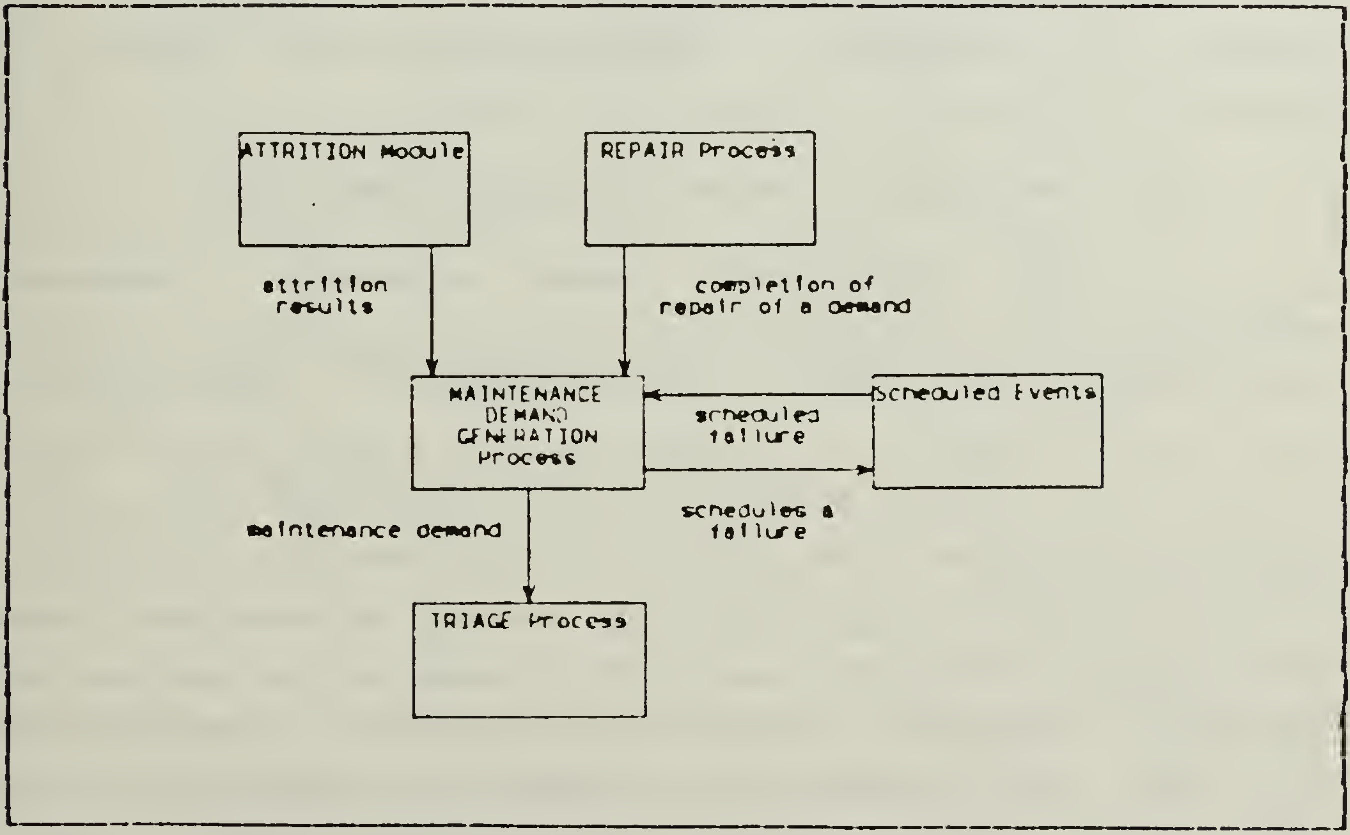


Figure 4.2 Maintenance Demand Generation Component.

b. Maintenance Demand Scheduling Component

The maintenance demand scheduling component begins with the generation of a maintenance demand. This demand is input to the triage process. The triage process either schedules repair, repair parts requests, or both at the maintenance entity; schedules organic recovery of the demand to the supporting maintenance entity; requests evacuation of the demand to the supporting maintenance entity; requests recovery support from the supporting maintenance entity;or declares the demand non-repairable and schedules salvage. If the demand is not scheduled for repair at the current maintenance entity, the demand is perpetuated as a supplemental demand to the supporting maintenance entity and input again to the triage process. This cycle continues until the demand is scheduled for repair or declared as salvage. This sequence of the maintenance demand scheduling component is shown in figure 4.3.

c. Maintenance Demand Execution Component

The maintenance demand execution component begins with the scheduling of a demand for recovery, repair parts supply, or repair. If the demand is scheduled for repair parts supply, it is input to the repair parts supply process which requisitions the needed parts and upon receipt schedules the demand for repair. Once a demand is scheduled for repair it is input to the repair process and upon completion submitted to the return process which updates the owning unit equipment status and returns the equipment to that unit. If the demand is scheduled for recovery, it is input to the recovery process and upon completion a supplemental demand is generated and input to the maintenance demand scheduling component. This sequence of the maintenance demand execution component is shown in figure 4.4.

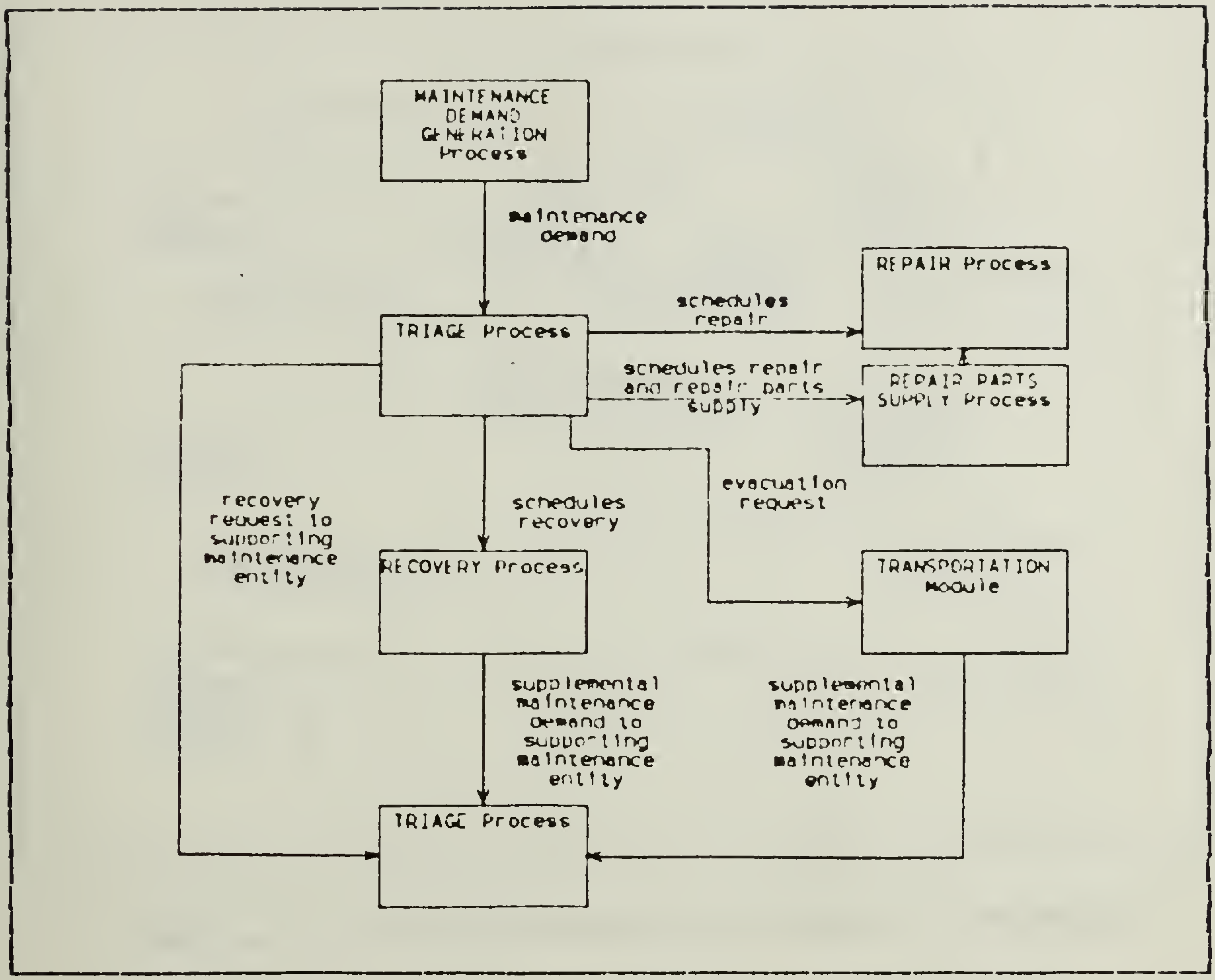

MAINTENANCE DEMAND GENERATION Process
maintenance demand
REPAIR Process
schedules repair
TRIAGE Process
schedules repair and repair parts supply
REPAIR PARTS SUPPLY Process
evacuation request
recovery request to supporting maintenance entity
schedules recovery
RECOVERY Process
TRANSPORTATION Module
supplemental maintenance demand to supporting maintenance entity
supplemental maintenance demand to supporting maintenance entity
TRIAGE Process

Figure 4.3 Maintenance Demand Scheduling Component.

d. Workload Prioritization Component

The workload prioritization component begins with either a change in a supported hierarchy's mission posture or the generation of the nth demand to a maintenance entity since the last priority update as input to the workload prioritization process. The result is the generation of an updated priority list for the maintenance entity which is subsequently used as input to the triage, repair, recovery, and repair parts supply processes. This sequence of the workload prioritization component is shown in figure 4.5.

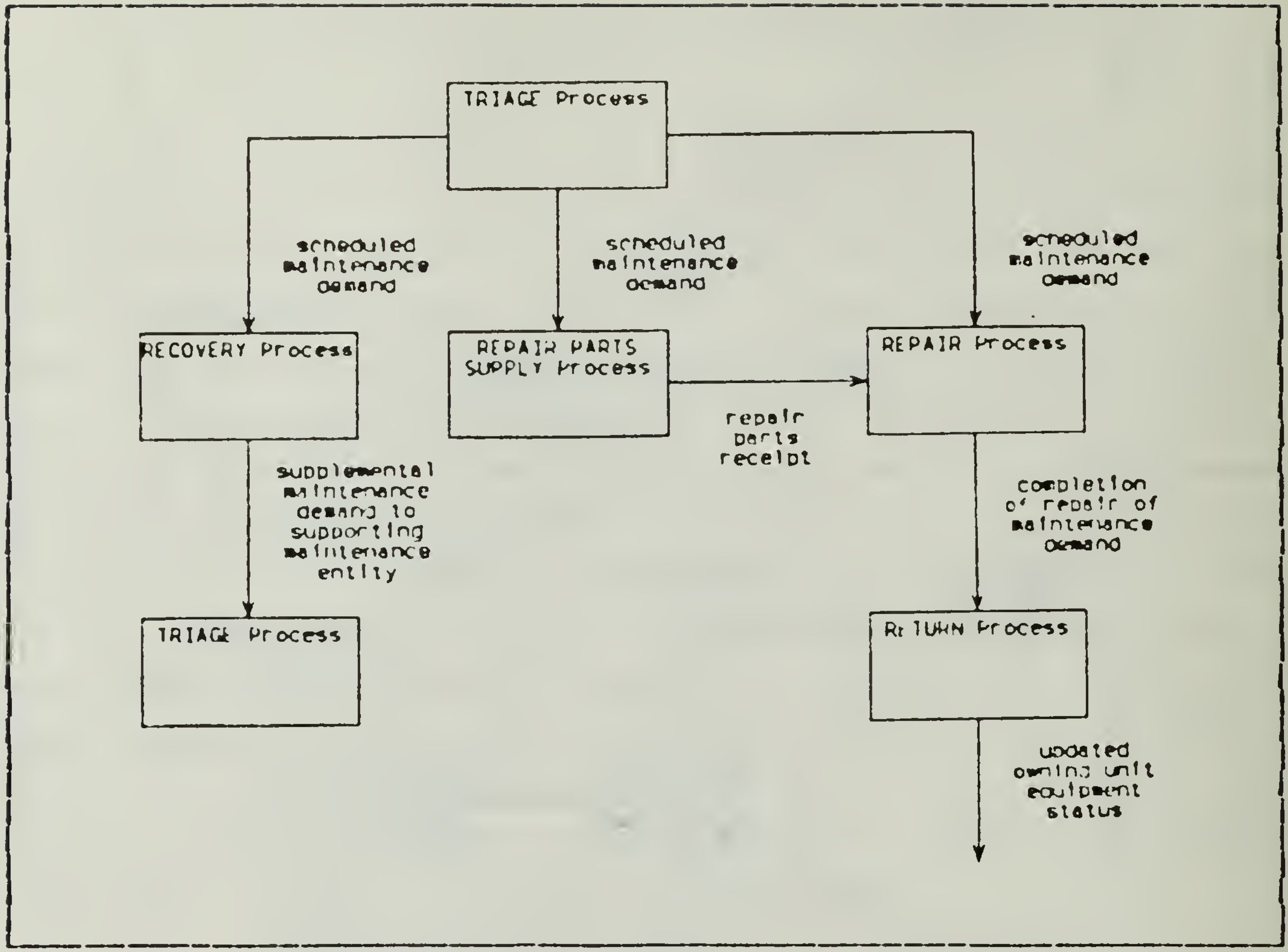

TRIAGE Process
scheduled maintenance demand
scheduled maintenance demand
scheduled maintenance demand
RECOVERY Process
REPAIR PARTS SUPPLY Process
REPAIR Process
repair parts receipt
supplemental maintenance demand to supporting maintenance entity
completion of repair of maintenance demand
TRIAGE Process
RETURN Process
updated owning unit equipment status

Figure 4.4 Maintenance Demand Execution Component.

e. Maintenance Time Criteria Determination Component

The maintenance time criteria determination component begins with the input of a change in a supported unit's mission posture, the receipt of the nth demand of a personnel type since the last update, or the occurrence of an entity's movement work capability change time. This input initiates the maintenance time criteria determination process which generates a new set of maintenance time criteria for each personnel type of the maintenance entity. These new maintenance time criteria are subsequently used as input to the triage process. This sequence of the

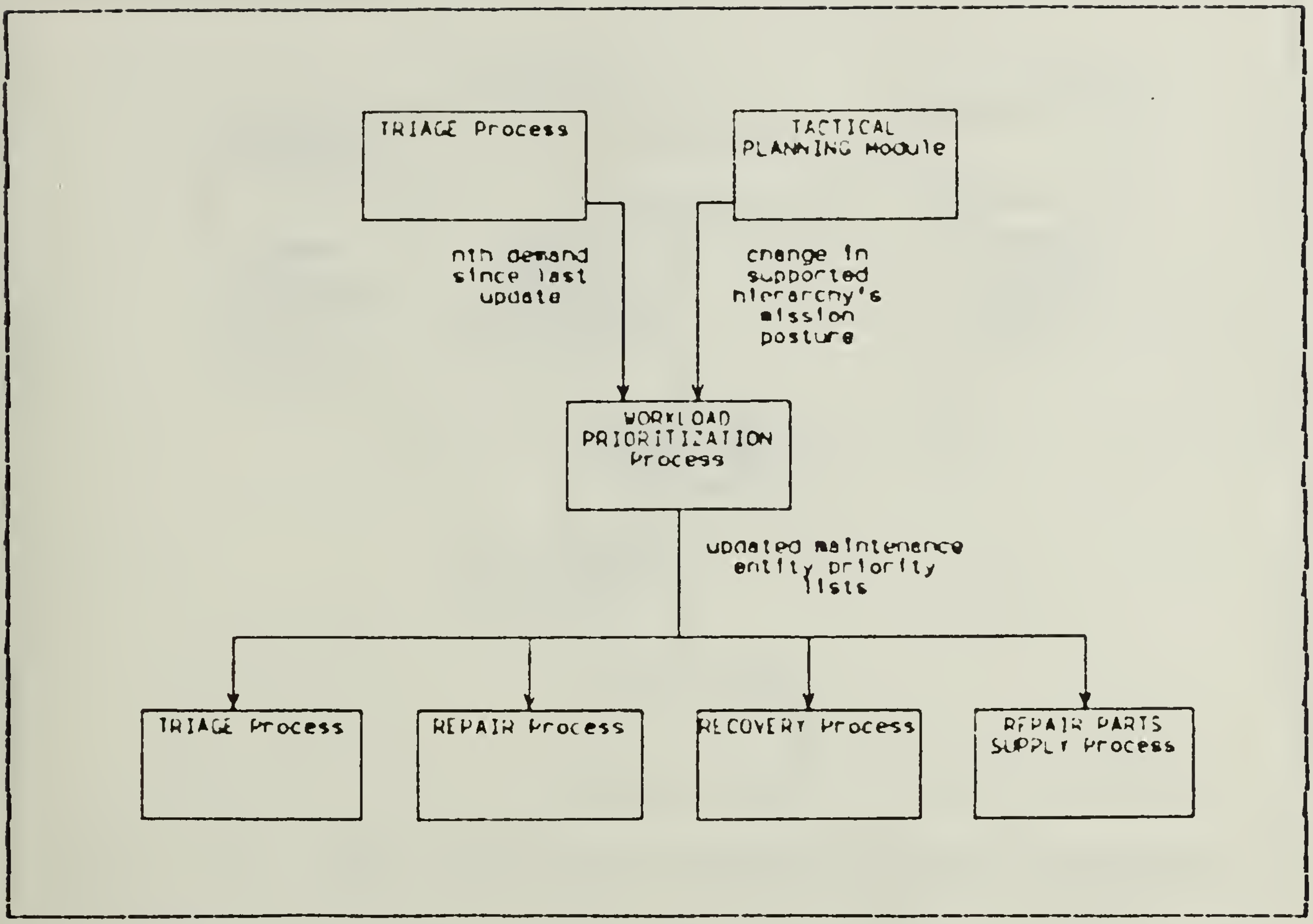

TRIAGE Process
TACTICAL PLANNING Module
nth demand since last update
change in supported hierarchy's mission posture
WORKLOAD PRIORITIZATION Process
updated maintenance entity priority lists
TRIAGE Process
REPAIR Process
RECOVERY Process
REPAIR PARTS SUPPLY Process

Figure 4.5 Workload Prioritization Component.

maintenance time criteria determination component is shown in figure 4.6.

f. Work Capability Change Forecast Component

The work capability change forecast component begins with the input of an updated movement time forecast for the current operations order/plan, due to the violation of a maintenance entity's minimum distance from the enemy, maximum distance from its supported units, or maximum communications distance from its supporting maintenance entity. From this input the process generates a set of work force capability change times for the maintenance entity. Each of these times is input to the MTC determination component at the scheduled time. This sequence of the work capability change forecast component is shown in figure 4.7.

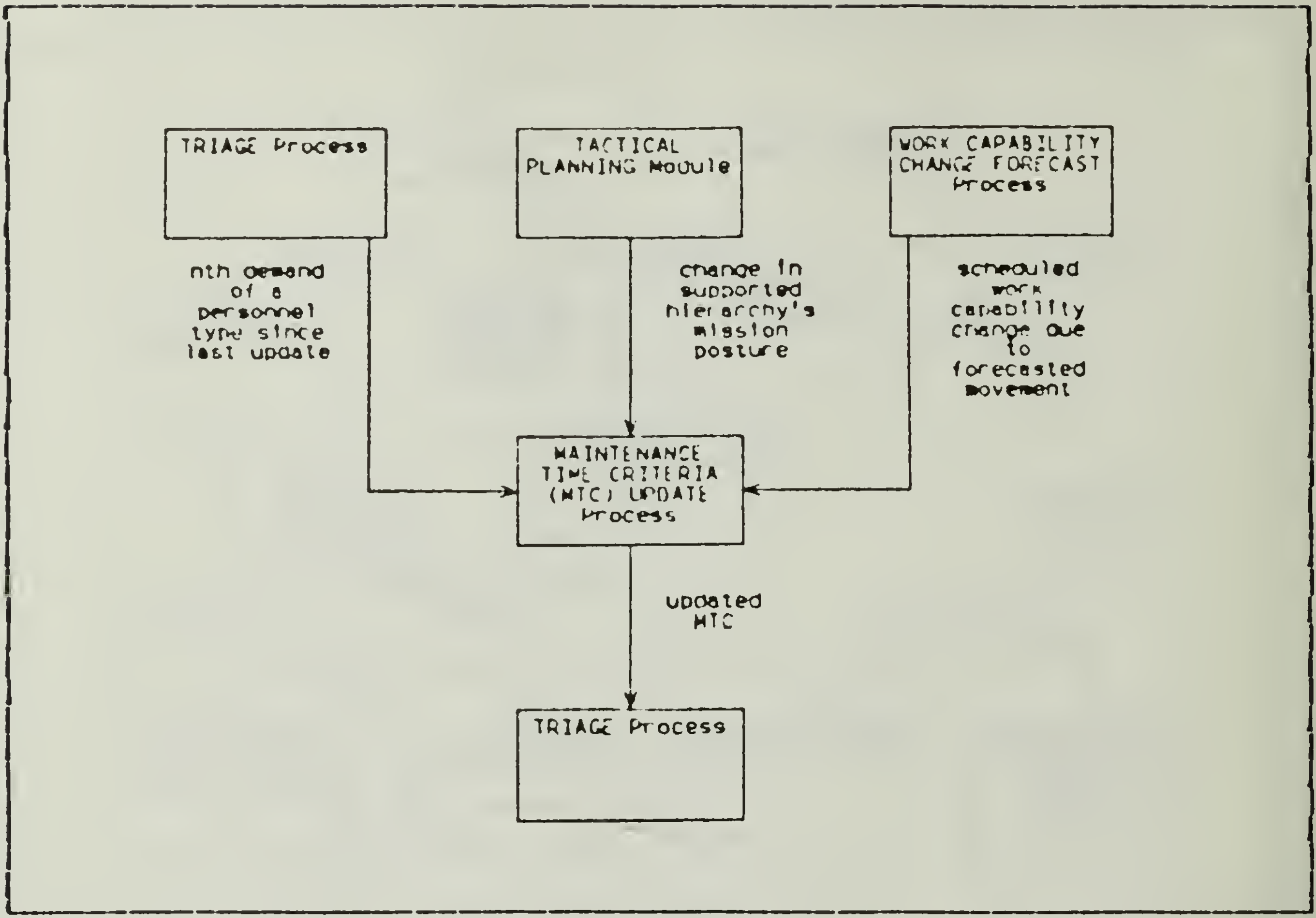

TRIAGE Process
TACTICAL PLANNING Module
WORK CAPABILITY CHANGE FORECAST Process
nth demand of a personnel type since last update
change in supported hierarchy's mission posture
scheduled work capability change due to forecasted movement
MAINTENANCE TIME CRITERIA (MTC) UPDATE Process
updated MTC
TRIAGE Process

Figure 4.6 Maintenance Time Criteria Update Component.

g. Reporting Component

The reporting component is initiated by the input of the occurrence of a required report interval time or the violation of a planning threshold at a maintenance entity. This input initiates the reports process which generates the appropriate report and schedules the sending of the report over the proper communications line to the proper reporting headquarters. These submitted reports are subsequently used to update the status files of the supporting maintenance entity for use as input to the MTC determination component or the workload prioritization component. This sequence is shown in figure 4.8.

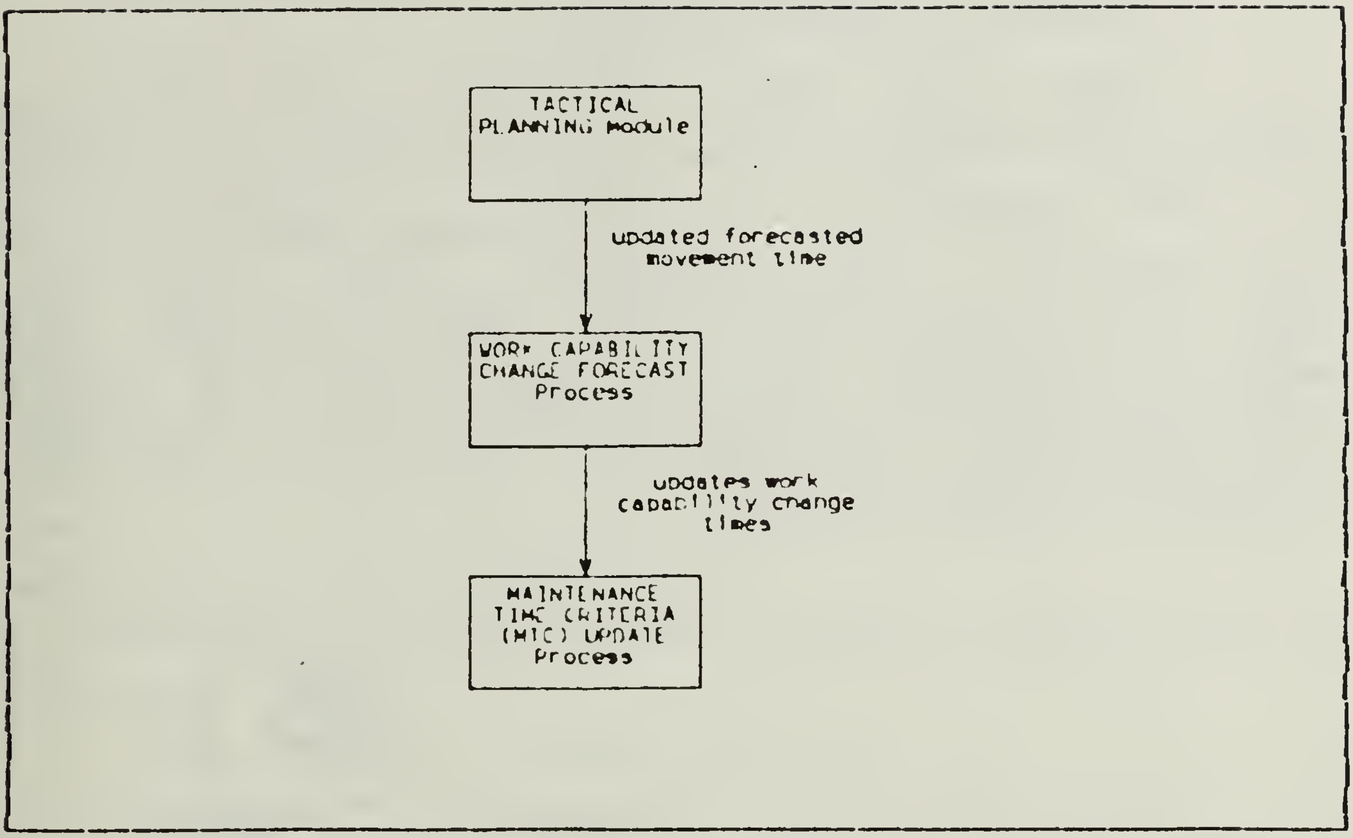

TACTICAL PLANNING Module
updated forecasted movement time
WORK CAPABILITY CHANGE FORECAST Process
updates work capability change times
MAINTENANCE TIME CRITERIA (MTC) UPDATE Process

Figure 4.7 Work Capability Change Forecast Component.

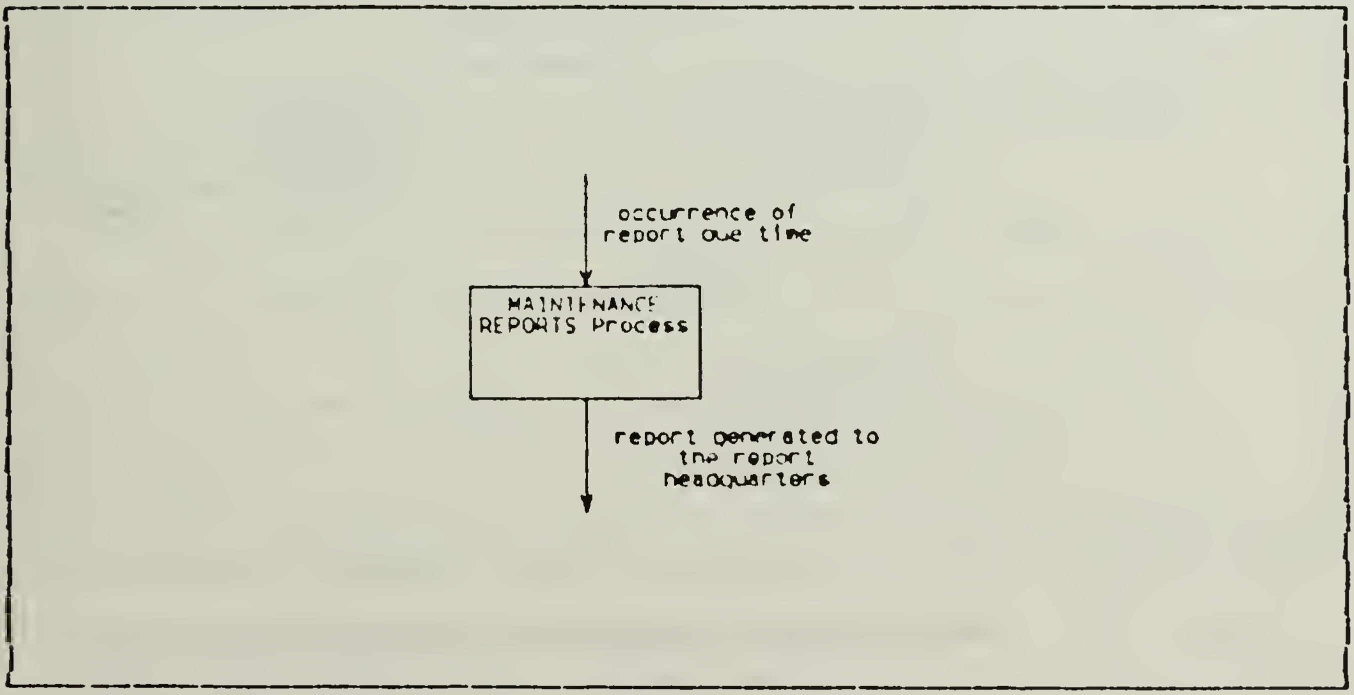

occurrence of report due time
MAINTENANCE REPORTS Process
report generated to the report headquarters

Figure 4.8 Reporting Component.

2. Component Interrelationship

Each of the seven components of the maintenance support model mentioned in the previous subsection interacts with other component(s) of the maintenance support model and with components of the other models of the combat model. These interrelationships are the cohesive elements which cement the components into a dynamic maintenance support functional model. A pictorial depiction of these interrelationships is shown in figure 4.9.

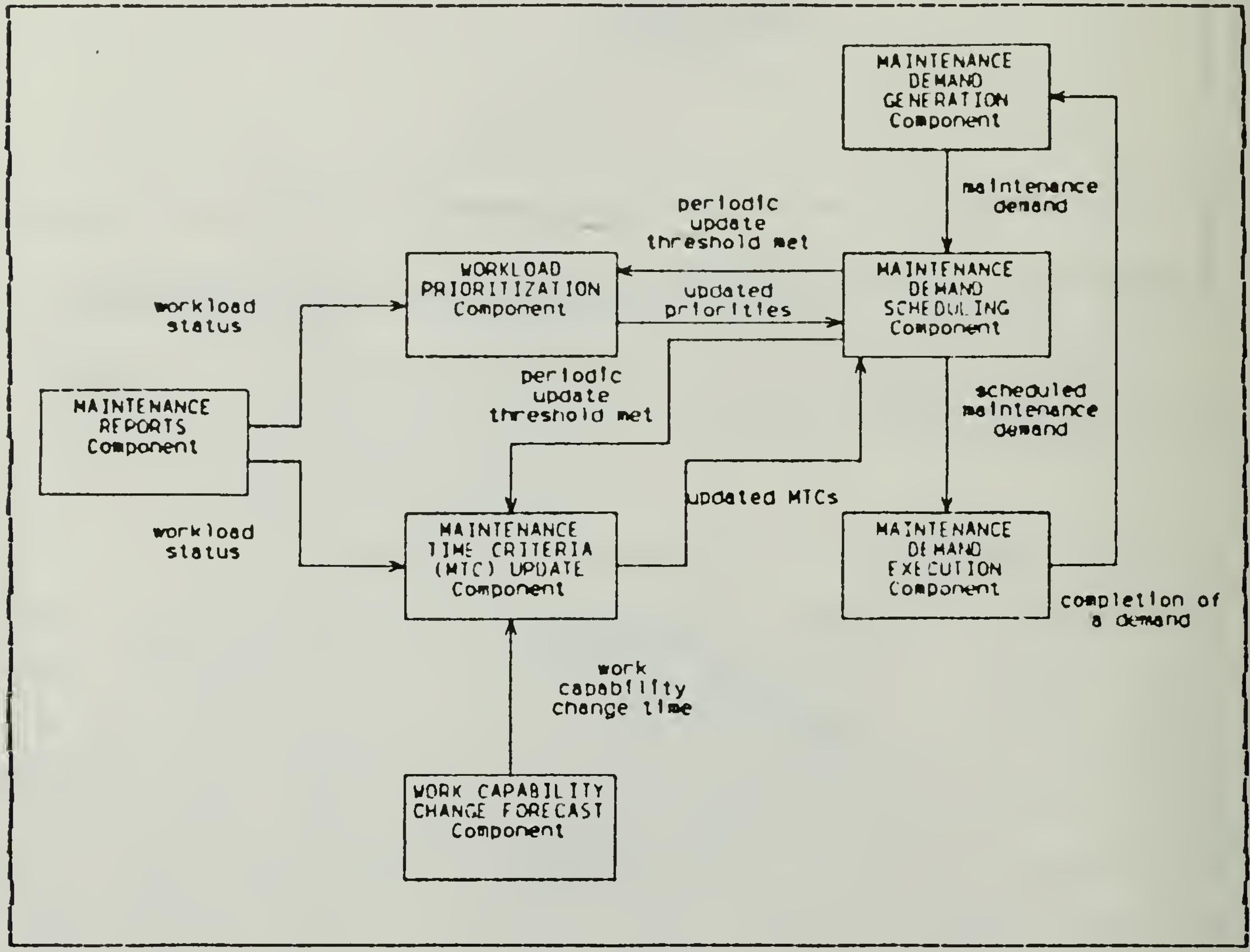

MAINTENANCE DEMAND GENERATION Component
maintenance demand
periodic update threshold met
WORKLOAD PRIORITIZATION Component
updated priorities
MAINTENANCE DEMAND SCHEDULING Component
workload status
MAINTENANCE REPORTS Component
periodic update threshold met
scheduled maintenance demand
updated MTCs
workload status
MAINTENANCE TIME CRITERIA (MTC) UPDATE Component
MAINTENANCE DEMAND EXECUTION Component
completion of a demand
work capability change time
WORK CAPABILITY CHANGE FORECAST Component

Figure 4.9 Maintenance Component Interrelationships.

D. SPECIFIC PLANNING PROCESSES DEVELOPED

An algorithm for each of the following three planning processes was developed for the maintenance support model:

1. Triage.
2. Workload prioritization.
3. Maintenance time criteria update.

The complete detailed algorithms are found in Appendix C. The format of the algorithms in Appendix C is "pseudo-code" from which a programmer can build actual subroutines in a specified computer language. A listing of variable and list definitions is found in Appendix B.

The following three planning process algorithms were not developed:

1. Work capability change forecast.
2. Allocation of maintenance entities for support.
3. Allocation of MSTs for temporary forward deployment.

The work capability change forecast process algorithm was not developed at this stage of research since neither a unit movement model nor a transportation model have been developed for the Airland Research Model as yet. Without a firm concept of the unit movement decision process and transportation allocation process, design of the work capability change forecast process is premature.

The allocation of maintenance support teams (MSTs) for temporary forward deployment process algorithm's development is delayed until a basic maintenance support model portraying fixed support allocations is operational. The complexity of this forward deployment decision process and its dynamic interaction with all other maintenance processes requires the insight of simulation results from a first stage model to assist algorithm development.

The allocation of maintenance entities for support process algorithm's development is also delayed until both a basic division level maintenance support model and Corps level maintenance support model are designed and operational. This allocation process is the mission of the Division Materiel Management Center (DMMC) and it involves the allocation of both division and operationally controlled (OPCON) Corps maintenance assets. Initial simulations with fixed support allocations will provide crucial insight as to methods of modelling this complex allocation process.

In the following subsections, a general description of each developed algorithm is presented in a format similar to that of Software Documentation Design Language (SDDL) to provide an overall view of each planning process. The SDDL method was chosen as the means for presentation vice flowcharts because the SDDL method is the current accepted standard in the military modelling community. The step numbers given are identical to those in the algorithms in Appendix C.

1. Triage Process

The triage planning process model represents the maintenance demand scheduling process of a maintenance entity. The model is a sequential comparison of repair completion time forecasts to a repair completion time threshold (maintenance time criteria - MTC). If this threshold is exceeded, then the scheduling of recovery or evacuation is modelled; otherwise the scheduling of repair is accomplished by placing the demand in the maintenance entity's waiting repair queue. The scheduling of recovery is modelled by comparing a forecasted recovery completion time to a recovery completion time threshold. Organic recovery assets are scheduled if this recovery completion time threshold is not exceeded; otherwise a request to a supporting maintenance entity is generated for accomplishment of the recovery task.

This model of the triage planning process differs from the real world method of conducting the process in that ad hoc mathematical formulas are used to obtain forecasted repair or recovery completion times rather than the heuristic methods of the real world. The actual heuristic forecasting methods are unknown and ill defined in actual practice. However, the ad hoc mathematical formulas are based upon this author's experience in making such heuristic forecasts and attempts to capture the significant variable involved in forecasting these completion times.

The step sequence of the triage planning process is given below with step numbers identical to the algorithm in Appendix C:

1. Increment the total demand counter of the maintenance entity.
2. Determine the type of demand. If the type is recovery request go to the recovery allocation steps of the process (steps 15-18).
3. Determine the repairability of the item of equipment. If it is non-repairable go to the recovery steps of the process (steps 15-18).
4. Determine the repair level required for the demand. If the repair level exceeds the repair level of the maintenance entity go to the recovery allocation steps of the process (steps 15-18).
5. Determine the expected repair time in manhours for each personnel type required for the demand, conditioned on the assumption of immediate availability of all personnel, equipment, and parts. Also, determine the number of each personnel type needed and increment the demand counter for each appropriate personnel type by one.
6. Determine the conditional repair time in clock hours for each personnel type.

7. Make a first feasibility check to repair at the current maintenance entity. If any conditional repair time for a personnel type is greater than the maintenance time criteria for that personnel type at the current maintenance entity, go to the recovery allocation steps of the process (steps 15-18).
8. Determine the repair parts requirements for the demand and the available sources of the parts (controlled exchange, cannibalization, supply stockage). Then determine the total forecasted parts acquisition time for each personnel type.
9. Determine the expected completion time for each personnel type in clock hours as if the demand was repaired at the current maintenance entity using only available assets.
10. Make a final feasibility check for repair at the current maintenance entity. If any expected completion time for a personnel type is greater than either the maintenance time criteria for that personnel type or the forecasted movement time of the current maintenance entity go to the recovery allocation steps of the process (steps 15-18).
11. Schedule the appropriate execution processes: repair, repair parts supply, or both. Then place the demand on the appropriate waiting execution list (queue).
12. Check the current maintenance entity's total demand counter and divide it by the preset number of demand receipts between priority updates - n. If the remainder equals zero call the Workload Prioritization process.
13. Check if any of the demand counters by personnel type exceeds the preset number of demand receipts of a specific personnel type between maintenance time

criteria updates - n. This n may be identical to the n in the step above. For a personnel type demand counter exceeding n, calculate the current maintenance entity's current total workload for that personnel type in manhours and call the Maintenance Time Criteria Update process.

14. Stop.
15. Begin recovery allocation steps. Determine the type recovery vehicle needed to recover the demand and whether that type recovery vehicle is available at the current maintenance entity. If that type vehicle is not available, place the demand on the entity's waiting recovery list and generate a new identical demand (with demand type of recovery request) to the supporting maintenance entity.
16. Add the demand to the waiting recovery list of the current maintenance entity according to its maintenance priority.
17. Determine the forecasted transport time by calling the transportation model. Then determine the total expected recovery mission completion time in clock hours.
18. Conduct a feasibility check of the expected total recovery mission completion time against the recovery time criteria of the maintenance entity. If the expected total mission time exceeds the recovery time criteria generate a new identical demand (with demand type of recovery request) to the supporting maintenance entity and place the demand on the current maintenance entity's waiting recovery list. Otherwise, schedule the recovery execution process.

2. Workload Prioritization Process

The workload prioritization process model represents the dynamic prioritization process of a maintenance entity's workload. This process is modelled as a two step process. First, the determination of supported unit maintenance priorities is modelled by setting them equal to the current tactical unit priorities. Second, the determination of equipment type maintenance priorities is modelled by grouping the equipment types into two groups: primary weapon systems of the supported units and all other equipment types. These two groups of equipment types are then ordered by increasing current operational readiness rates.

This model of dynamically prioritizing a maintenance entity's workload differs from the real world process in that the two prioritization schemes are ad hoc formulations intended to represent the essential factors involved in prioritizing maintenance workloads. In actual real world practice, personal judgments and heuristic forecasting of the nature of the future workload are the basis of prioritization. However, these heuristic forecasts and judgments are not well defined as decision criteria. The prioritization schemes formulated offer an initial dynamic prioritization decision criteria methodology. The formulated method should not differ significantly from actual practice since unit priorities should logically be dependent upon the tactical unit priorities and equipment priorities should be dependent upon the unit priorities and the current combat importance of the equipment type.

The step sequence of the workload prioritization planning process is:

1. Determine the maintenance entity's hierarchical level. If the hierarchical level is company level go to step 3.

2. Set the maintenance entity's unit priorities equal to the supported hierarchy's tactical unit priorities.
3. Update the equipment priorities by ordering the equipment types according to the following scheme: group by pacing (unit primary weapon systems) items and all other items; then within each of these two groups order the equipment types by increasing operational readiness rates aggregated at the supported hierarchy level.
4. Stop.

3. Maintenance Time Criteria Update Process

The maintenance time criteria update process model represents the dynamic updating of the repair completion time thresholds (MTCs) for each personnel type of a maintenance entity. This updating is modelled by proportionally changing an MTC for a personnel type by the identical proportionally change in the personnel type work capability of the maintenance entity.

In the real world, maintenance time criteria are seldom updated. When they are updated, the update is usually in response to a change in the tactical mission of the supported unit. However, the concept of maintenance time criteria was designed with a goal of distributing the maintenance workload among the total hierarchy of maintenance assets. The model procedure of dynamically updating the maintenance time criteria provides an initial methodology for dynamically updating MTC and can provide results which yield insight into better methodologies for distributing the maintenance workload.

The step sequence of the maintenance time criteria update process is:

1. Determine the type of input: mission posture change, periodic, or work capability change for movement. If

the type input is mission posture change go to step 2. If the type input is periodic go to step 3. If the type input is work capability change for movement go to step 4.

2. Update all maintenance time criteria for each personnel type of the maintenance entity by conducting a table look up and matching the new mission posture of the supported hierarchy to appropriate maintenance time criteria. Go to step 5.
3. Determine the maintenance entity's workload capability and upper and lower workload thresholds for each personnel type. If either threshold is violated by the current workload of a personnel type, change the maintenance time criteria for that personnel type proportionally according to the magnitude of the deviation of the current workload from the workload capability. Go to step 5.
4. Determine the proportional change in the work capability and change the maintenance time criteria for the appropriate personnel type by an identical proportion. Go to step 6.
5. Set the demand counter for each appropriate personnel type to zero.
6. Stop.

V. SUMMARY AND DIRECTIONS FOR FURTHER RESEARCH

A. SUMMARY

This thesis has presented an explicit, sequential event structural design for the initial stage maintenance support model in support of the Airland Research effort. The thrust of the design of the module was to develop specific rule-based decision algorithms in support of both planning and execution processes and to identify the functions within the maintenance support system requiring modelling. Algorithms with dynamic decision criteria were developed for three specific maintenance support planning processes which have heretofore been undeveloped within the military modelling community.

The formulated planning algorithms provide an initial set of cohesive algorithms for building an initial stage vertical slice maintenance support model. The subsequently developed initial maintenance support model can provide the means of studying the maintenance support functions in tandem with some type of combat feeder model in order to develop a largely implicit maintenance support model capable of variable resolution for the Airland Research Model.

B. DIRECTIONS FOR FURTHER RESEARCH

Full scale development and completion of the maintenance support module requires further research in several areas. Some of these research areas and recommended directions for that research are presented below.

Currently, research is underway to examine the issue of tactical movement planning and decision logic utilizing unit mission posture templating. Once this research begins to come to fruition, insights into the interrelationship between the combat unit movement planning and the movement of logistical support areas will surface. Then the maintenance support module's work capability change forecast process can be developed.

More in-depth research of data sources for the maintenance support module should be started next. In particular, research must be guided towards development of combat damage distributions for specific weapon systems. Additionally, an effort towards gaining reliable repair time and failure distribution data from the exercises conducted at the National Training Center must be initiated.

A more detailed study of the AURA model maintenance support execution modelling methodology must be conducted. Its flexible structure allows the user to define a wide range of personnel skills, repair parts, and maintenance tasks. In particular, its networking of maintenance tasks can provide an analytical method for simulation studies of the maintenance execution process for aggregation purposes. This model can also provide a foundation for development of maintenance execution processes.

Once the execution processes are developed and an initial maintenance support module is operational, the issue of dynamic allocation of maintenance support assets must be examined. This is a crucial step towards integrating the Corps level maintenance support structure with the division level structure.

Methods of aggregation of the level of resolution of maintenance demands can also be further researched once an initial module is operational. An aggregation methodology would reduce the need for large data storage and data base requirements without sacrificing fidelity of the output.

Enhancements to the developed planning processes could be male by integrating operational readiness float (ORF) and the play of terrain stuck weapon systems into the decision logic. These could be readily added in once an initial module is operational.

Finally, examination of the development of a generalized value system is also underway. The creation of such a generalized value system which expresses the combat value of combat entities should provide the basis for establishing tactical unit priorities which are the basis of unit maintenance priorities.

Examination of the combat value of maintenance entities must also be pursued. On the surface the direct contribution of maintenance entities to combat is the rapid return of weapon systems albeit firepower units to the combat entities. The development of a methodology to express this contribution can provide decision criteria for allocation of maintenance assets in support of the whole combat structure being studied.

However, such an expression of the value of a maintenance entity for the purpose of an opposing force's deep interdiction targeting allocation is inappropriate. An opposing force is unlikely to possess intelligence data in sufficient detail and time relevance to assess the direct contribution of a maintenance entity to an enemy's combat capability. A possible method to use for such targeting purpose is to forecast the outcome of a planned operation both with and without the candidate maintenance entity target. This would provide a basis for assessing the worth of that maintenance entity and thus, its interdiction worth.

APPENDIX A
GLOSSARY

A. INTRODUCTION

This glossary consists of two parts. The first part is a listing of operational terms and their definitions. The second part is a listing of acronyms and their meanings.

B. OPERATIONAL TERMS AND DEFINITIONS

AirLand Battle (ALB): The AirLand Battle concept outlines an approach to military operations which realizes the full potential of U.S forces. Two ideas -- extending the battlefield and integrating conventional, nuclear, chemical and electronic means -- are combined to describe a battlefield where the enemy is attacked to the full depth of his formations [Ref. 13: p. B-1].

Attachment: The temporary placement of units or personnel in an organization. Subject to limitations imposed by the attachment order, the commander of the formation, unit, or organization receiving the attachment will exercise the same degree of command and control as he does over units and persons organic to his command. However, the responsibility for transfer and promotion of personnel will normally be retained by the parent formation, unit, or organization [Ref. 13: p. B-5].

Authorized stockage list (ASL): In a repair parts supply context, an authorized stockage list describes the quantity and nomenclature of repair parts authorized for stockage at a direct support unit (DSU) for a specified time frame of support, e.g. 30 day level of support. This list must include all repair parts on the supported units' prescribed load lists (PLLs) and those repair parts required to perform direct support level maintenance tasks. The quantities stocked are determined by command decision and/or by demand rate. The ASL is reconstituted as it is used [Ref. 2: p. 5-18].

Battle damage assessment (BDA): An inspection of inoperable equipment and a determination of the maintenance actions required to return it to a combat serviceable condition [Ref. 4: p. 5-22].

Cannibalization: The authorized removal of serviceable and unserviceable assemblies from unserviceable, uneconomically repairable (salvage), or excess end items of equipment authorized for local disposal. When done on the battlefield, cannibalization has the final aim of returning as many weapon systems to the battle as quickly as possible [Ref. 4: p. 2-6].

Combat trains: The portion of unit trains that provides the combat service support required for immediate response to the needs of forward tactical elements [Ref. 13: p. B-7].

Controlled exchange: The removal of serviceable parts from unserviceable, economically repairable equipment for instant use in restoring a like item to a serviceable condition. The unserviceable part must be repaced or affixed to the item from which the serviceable part was removed [Ref. 4: p. 2-6].

Deep attack: The use of long range interdiction to gain local battlefield advantages. It may consist of the use of firepower, maneuver, or both [Ref. 3: p. 7-13].

Direct exchange (DX): A method of repair parts supply whereby using units deliver unserviceable but DS repairable items or components and exchange them for serviceable ones at a direct support unit. DX items comprise a portion of the division ASL and are repaired within the division by DS maintenance units [Ref. 4: p. 4-24].

Direct support (DS): The support provided by a unit or force not attached or under command of the supported unit or force, but required to give priority to the support required by that supported unit or force [Ref. 13: p. B-11].

Evacuation: The movement of equipment from supporting maintenance units to other combat service support (CSS) activities in order to continue the maintenance repair process [Ref. 4: p. 3-14].

Field trains: The portion of the unit trains that provides the combat service support not required for immediate response to the needs of tactical elements. They are located rearward to prevent interference with the tactical operation [Ref. 13: p. B-13].

General support (GS): Support that is given to the force as a whole and not to any particular subdivision. A mission which is frequently assigned to combat support and combat service support (CSS) units. For example, a division field artillery battalion assigned to a general mission operates under the control of the division artillery headquarters while supporting the whole division [Ref. 13: p. B-15].

Ground support maintenance: A broad commodity oriented categorization of maintenance support which excludes maintenance of airdrop, aviation, medical, missile, and textile equipment.

Maintenance: All action taken to retain materiel in a serviceable condition or to restore it to serviceability [Ref. 2: p. 7-1].

Maintenance collection point (MCP): The location established by DS maintenance units to which unserviceable equipment is recovered for maintenance processing and from which unserviceable equipment is evacuated for salvage or repair.

Maintenance time criteria (MTC): A key management tool for maintenance. Estimated repair time limits are established at each maintenance level to provide guides for repair, recover, and evacuate decisions. The goal of MTC is to distribute the maintenance workload among the total division maintenance resources [Ref. 4: p. 5-23].

Operational control (OPCON): The authority delegated to a commander to direct forces so that he may accomplish specific missions or tasks which are usually limited by function, time, or location; and to deploy units and retain or assign tactical control of those units. It does not include administrative or logistic responsibility, discipline, internal organization, or unit training [Ref. 13: p. B-23].

Operational readiness float (ORF): Selected end items (weapon systems) or major components that are authorized for stockage at support maintenance activities to increase their support capability. These items are used to replace supported unit equipment which cannot be repaired in time to meet operational requirements. The item needing repair is retained by the maintenance activity, repaired, and returned to ORF stock [Ref. 4: p. 4-25].

Prescribed load list (PLL): In a repair parts context, a prescribed load list describes the quantity and nomenclature of repair parts authorized for stockage at organizational maintenance activities for a specified time frame of support, e.g. a 15 day level of support. The list consists of those repair parts and other maintenance related items required to perform authorized organizational maintenance tasks [Ref. 4: p. 5-18].

Preventive maintenance: Operator/crew and organizational maintenance level checks and services. This is done at the using unit level and is the most important maintenance function performed [Ref. 4: p. 2-6].

Rear area combat operations (RACO): Operations undertaken in the rear area to protect units, lines of communication, installations, and facilities from enemy attack, sabotage, from natural disaster, to limit damage, and reestablish support capabilities [Ref. 13: p. B-25].

Recovery: The function of removal of equipment from the battlefield by organizational maintenance personnel for purposes of initiating maintenance repair processing [Ref. 4: p. 3-13].

Triage: The process of classifying inoperable equipment and developing a maintenance action plan for returning the maximum number of items to operation. The first step is battle damage assessment. The second step is a feasibility check for availability of maintenance resources - personnel, tools, parts, equipment - and time. This step includes checking for cannibalization or controlled exchange for parts or forward deployment of supporting maintenance teams. Finally, an action plan is developed for repair or disposition of all inoperable equipment at the location [Ref. 4: p. 5-12].

Unit trains: Combat service support personnel and equipment organic or attached to a force that provides supply, evacuation, and maintenance services. Unit trains, whether or not echeloned, are under unit control with no part of them released to the control of higher headquarters. They are normally echeloned into combat and field trains [Ref. 13: p. B-31].

Unserviceable equipment rally point (UERP): The location at which a battalion organizational maintenance platoon collects unserviceable equipment of the battalion. It is the focal point of the platoon's maintenance effort.

C. ACRONYMS

ADP: automatic data processing

A/L: administrative/logistic

ALB: AirLand Battle

ASL: authorized stockage list

BDA: battle damage assessment

BMO: battalion maintenance officer

BMT: battalion maintenance technician

BSA: brigade support area

COMSEC: communications security

DISCOM: Division Support Command

DMMC: Division Materiel Management Center

DS: direct support

DSA: division support area

DX: direct exchange

FSB: Forward Support Battalion

GS: general support

LCSS: Land Combat Support System

MAC: maintenance allocation chart

MCP: maintenance collection point

MEMO: mission essential maintenance only

MSB: Main Support Battalion

MST: maintenance support team

MT: maintenance team

MTC: maintenance time criteria

OPCON: operational control

ORF: operational readiness float

PLL: prescribed load list

RAC: rear area combat

RACO: rear area combat operations

RAS: rear area security

UERP: unserviceable equipment rally point

XO: executive officer

1SG: first sergeant

APPENDIX B

ALGORITHM VARIABLES AND DATA LISTS

This appendix gives the meanings and sources of all variables and data lists used by the algorithms in Appendix C.

A. VARIABLES

1. AWLDEV(k): Acceptable workload deviation. This is the allowable deviation in workload manhours by personnel type k of a maintenance entity. It is an attribute of a maintenance entity. Its source is external and must be set during model initialization.
2. CE: Controlled exchange switch. It is an on-off switch which indicates whether a MAINTDMD requires parts acquisition by controlled exchange or cannibalization. It is an attribute of a MAINTDMD. The CE switch is activated by the TRIAGE process.
3. CEPAT(RP): Controlled exchange part acquisition time for a repair part code RP. It is an attribute of a MAINTDMD. Its source is the PART INSTALLATION AND REMOVAL List which is an external data source.
4. CEPTR: Controlled exchange pointer. This is a pointer to the MAINTDMD which is to be the controlled exchange part source for another MAINTDMD. It is an attribute of a MAINTDMD. CEPTR is set by the TRIAGE process.
5. CMTTR(k): The expected conditional mean time to repair for personnel type k in manhours. It is an attribute of a MAINTDMD. Its source is the REPAIR TIME List which is an external data source.

6. CRT(k): Conditional repair time for personnel type k in clock hours. It is an attribute of a MAINTDMD. It is calculated by the TRIAGE process.
7. CT: Current time. It is a model attribute maintained by the model.
8. CWLH(k): Current workload manhours for personnel type k. It is an attribute of a maintenance entity. It is calculated by the TRIAGE process.
9. DW: The set of MAINTDMDs on a maintenance entity's WAITING COMPLETION List which are not inprogress. It is determined by the TRIAGE process.
10. DEMAND COUNT(k): The current total count of MAINTDMDs requiring personnel type k for a maintenance entity. It is used to determine periodic MTC update times. It is an attribute of a maintenance entity. It is adjusted by both the TRIAGE and MTC UPDATE processes.
11. DEMANDTYPE: This variable indicates the type of MAINTDMD - report, recovery request, or repair request. It is an attribute of a MAINTDMD. Its source is the MAINTENANCE DEMAND GENERATION process or TRIAGE process.
12. ERC: Equipment repair code. This variable identifies the type of repair required for the particular equipment type and MAINTDMD. It is an attribute of a MAINTDMD. It is determined by the MAINTENANCE DEMAND GENERATION process using external data sources of equipment failures or damage distributions.
13. ERT: Expected recovery time. It is an attribute of a MAINTDMD. It is calculated by the TRIAGE process.
14. ET: Equipment type. It is an attribute of both a MAINTDMD and an entity. Its source is external for entities and must be input during the model initialization. For MAINTDMDs, it is generated by the input to the MAINTENANCE DEMAND GENERATION process.

15. ETC(k): Expected time of completion of repair by personnel type k of a MAINTDMD in clock hours. It is an attribute of a MAINTDMD. It is calculated by the TRIAGE process.
16. FMT: Forecasted movement time for an entity. It is an attribute of an entity. It is determined by the TACTICAL PLANNING Module.
17. FPAT(RP): Forecasted part acquisition time for repair part type RP in clock hours. It is an attribute of a MAINTDMD. It is calculated by the TRIAGE process.
18. FRT(k): Forecasted repair time for personnel type k of a MAINTDMD in clock hours. It is an attribute of a MAINIDMD. It is calculated by the TRIAGE process.
19. HL: Hierarchical level - company, battalion, brigade, or division. It is an attribute of a maintenance entity. Its source is external and is input during model initialization.
20. INTYPE: The input type of a call to the MTC UPDATE process - mission change, periodic, or work capability change. The process calling MTC UPDATE generates this variable.
21. IRD: The set of MAINTDMDs of a maintenance entity's WAITING RECOVERY List which are inprogress.
22. IWLH(k): The inprogress repair workload of personnel type k i manhours for a maintenance entity. It is calculated by the TRIAGE process.
23. KRP(k): The set of repair part codes - RPs - which require personnel type k for installation. It is an attribute of a MAINTCMD. Its source is the REPAIR PARTS List which is an external data source.
24. LWLT(k): The lower workload threshold for personnel type k of a maintenance entity in manhours. It is an attribute of a maintenance entity. It is calculated by the MTC UPDATE process.

25. MAINTDMD: A particular demand for maintenance support to a specific maintenance entity. It is generated by the MAINTENANCE DEMAND GENERATION process.

26. MP: Mission posture. This identifies the mission posture of an entity. It is an attribute of an entity. Its source is an external set of predetermined codes for specific type missions. It is determined by the TACTICAL PLANNING Module.

27. MTC(k): Maintenance time criteria for personnel type k of a maintenance entity. It is a repair completion time threshold in clock hours for a specific personnel type k and is an attribute of a maintenance entity. The initial set is found in the MISSION POSTURE MTC List which is an external data source. It is updated by the MTC UPDATE process.

28. N: The number of MAINTDMD receipts between periodic planning updates of a maintenance entity. It is an attribute of a maintenance entity. Its source is external and input during model initialization.

29. NM(k): The number of personnel type k required to repair a particular ERC. It is an attribute of a MAINTDMD. Its source is the REPAIR TIME List which is an external data source.

30. OR(ET): Current operational readiness rate of equipment type ET of an entity. It is an attribute of an entity. It is updated by the MAINTENANCE DEMAND GENERATION and RETURN processes.

31. OST(RP): The order and ship time for a repair part type RP. It is determined by the PART ACQUISITION FORECAST process of the SUPPLY Module.

32. PERSTYPE: The list of needed personnel types for an ERC and MAINTDMD. It is an attribute of a MAINTDMD. Its source is the REPAIR TIME List which is an external data source.

33. PWF: Productive work fraction of a maintenance entity. It is an expected percentage of a 24 hour period during which maintenance work is conducted by maintenance personnel. It is an attribute of a maintenance entity. Its source is external and input during the model initialization.

34. QP(k): The quantity of personnel type k currently available in a maintenance entity. It is an attribute of a maintenance entity. It is updated by the ATTRITION and PERSONNEL REPLACEMENT processes.

35. QRV(RVT): The quantity of recovery vehicles of type RVT currently available in a maintenance entity. It is an attribute of a maintenance entity. Its source is external and input during model initialization and updated by the ATTRITION, RETURN, and EQUIPMENT REPLACEMENT processes.

36. RC: Repairability code - repairable or non-repairable. It is an attribute of a MAINTDMD. Its source is the REPAIRABILITY List which is an external data source.

37. RECT: The forecasted travel time for a recovery mission both ways. It is an attribute of a MAINTDMD. It is calculated by the TRANSPORTATION Module.

38. RL: Repair level code - organizational, direct support, or general support. It is an attribute of a MAINTDMD and a maintenance entity. Its source for a MAINTDMD is the REPAIR LEVEL List which is an external data source. Its source for a maintenance entity is external and input during model initialization for a maintenance entity.

39. RP: Repair part code. It indicates the type repair code. It is an attribute of a MAINTDMD. Its source is the REPAIR PARTS List which is an external data source.

40. RPQ(RP): The quantity of repair part type RP needed for an ERC. It is an attribute of a MAINTDMD. Its source is the REPAIR PARTS List which is an external data source.

41. RTC: Recovery time criteria in clock hours. It is a recovery completion time threshold and an attribute of a maintenance entity. It is a static, user defined value.

42. RVT: Recovery vehicle type. It is an attribute of both a MAINTDMD and a maintenance entity. Its source for a MAINTDMD is the RECOVERY COMPATIBILITY List which is an external data source. Its source for a maintenance is external and input during model initialization.

43. RWLH(RVT): Recovery workload for recovery vehicle type RVT in clock hours for a maintenance entity. It is an attribute of a maintenance entity. It is calculated by the TRIAGE process.

44. SALVAGE: The salvage on-off switch for a MAINTDMD. It is an attribute of a MAINTDMD. It is activated by the TRIAGE process.

45. ST: Start time of execution of a MAINTDMD. It is an attribute of a MAINTDMD. It is set by the appropriate maintenance execution process.

46. TCEPAT(k): The total controlled exchange or cannibalization parts acquisition time for personnel type k of a MAINTDMD. It is an attribute of a MAINTDMD. It is calculated by the TRIAGE process.

47. TDCH(k): The total daily clock hours for personnel type k of a maintenance entity. It is calculated by the TRIAGE process.

48. TDRH(RVT): The total daily clock hours for recovery vehicle type RVT of a maintenance entity. It is calculated by the TRIAGE process.

49. TOTAL DEMAND COUNT: The current total count of demands received by a maintenance entity. It is an attribute of a maintenance entity. It is updated by the TRIAGE process.

50. ULWT(k): THe upper workload threshold for personnel type k in manhours. It is an attribute of a maintenance entity. It is calculated by the MTC UPDATE process.

51. WCCNBR: The work capability change number. This identifies the incremental step of a maintenance entity's workload capability change due to forecasted movement. Its source is the MOVEMENT WORK CHANGE List which is an external data source.

52. WCF(WCCNBR): Work capability change fraction. This identifies the magnitude of the work capability change at step WCCNBR of a maintenance entity due to forecasted movement. Its source is the MOVEMENT WORK CHANGE List which is an external data source.

53. WLC(k): The workload capability in manhours of personnel type k of a maintenance entity. It is an attribute of a maintenance entity. It is calculated by the MTC UPDATE process

54. WRD: The set of MAINTDMDs waiting recovery but not inprogress of a maintenance entity which precede the MAINTDMD being processed by the TRIAGE process. It is determined by the TRIAGE process using the maintenance entity's WAITING RECOVERY List.

55. WP: The attribute switch of a MAINTDMD indicating that it is waiting parts. It is an attribute of a MAINTDMD. It is activated by the TRIAGE process.

56. WWLH(k): The waiting repair workload of personnel type k in manhours for a maintenance entity. It is calculated by the TRIAGE process.

B. DATA LISTS

1. EQUIPMENT MAINTENANCE PRIORITY List: This is an attribute of a maintenance entity indicating the equipment priorities. It is updated by the WORKLOAD PRIORITIIZATION process.
2. MISSION POSTURE MTC List: An external data source of mission posture codes and matching MTC by maintenance entity hierarchical level and personnel type.
3. MOVEMENT WORK CHANGE List: An external data source of sets of WCF which are matched to an entity type or identifier based upon the entity's requirements for work transitioning to movement or vice versa.
4. PARTS INSTALLATION AND REMOVAL List: An external data source which matches repair part codes RPs to an installation and removal time for the part for the purposes of determining the controlled exchange or cannibalization times.
5. PARTS STOCKAGE List: An attribute of a maintenance entity which contains its authorized repair part codes, RPs, and their matching current stockage levels. Its initial values are input during model initialization. It is updated by both the REPAIR PARTS SUPPLY and TRIAGE processes.
6. RECOVERY COMPATIBILITY List: An external data source which matches equipment types - ETs - to required recovery vehicle types - RVTs .
7. REPAIR LEVEL List: An external data source which matches equipment repair codes - ERCs - to appropriate repair levels - RLs.
8. REPAIR PARTS List: An external data source which matches equipment repair codes - ERCs - to repair part codes - RPs - and personnel types - k - to repair part codes - RPs.

9. REPAIR TIME List: An external data source which matches equipment repair codes - ERCs - to appropriate required personnel types - k -, CMTTR(k)s, and NM(k)s.
10. REPAIRABILITY List: An external data source which matches equipment repair codes - ERCs - to appropriate repairability codes - RCs.
11. SALVAGE COMPATIBILITY List: An external data source which matches repair part codes - RPs - to appropriate equipment repair codes - ERCs - which can be a source of repair part - RP - via controlled exchange or cannibalization.
12. TACTICAL UNIT PRIORITY List: This is an attribute of a combat entity indicating the subordinate unit tactical priorities. It is updated by the TACTICAL PLANNING Module.
13. UNIT MAINTENANCE PRIORITY List: This is an attribute of a maintenance entity indicating the unit maintenance priorities. It is identical to the TACTICAL UNIT PRIORITY List of the supported hierarchical unit and updated by the WORKLOAD PRICRITIZATION process.
14. WAITING CE List: An attribute of a maintenance entity which identifies the MAINTDMDs waiting for controlled exchange or cannibalization to be performed by the REPAIR process.
15. WAITING COMPLETION List: An attribute of a maintenance entity which identifies all MAINTDMDs waiting repair - waiting repair, waiting parts, waiting controlled exchange or cannibalization, or inprogress.
16. WAITING PARTS List: An attribute of a maintenance entity which identifies the MAINTDMDs waiting parts.
17. WAITING RECOVERY List: An attribute of a maintenance entity which identifies all the MAINTDMDs waiting recovery or inprogress.

18. WAITING REPAIR List: An attribute of a maintenance entity which identifies all the MAINTDMDs waiting for repair only.

APPENDIX C

PLANNING DECISION PROCESS ALGORITHMS

A. TRIAGE PROCESS

PROCESS: TRIAGE

Activated by: MAINTDMD GENERATOR

Given:

1. The MAINTDMD(i,j).
2. The owning entity - i.
3. The maintenance entity - j.

Description:

Process TRIAGE models the decision process at a specified hierarchical level of determining the maintenance disposition of a disabled weapon system - MAINTDMD. The decision will either be to repair the disabled weapon system at the current hierarchical level or to recover or evacuate the weapon system to a higher supporting hierarchical level for repair or salvage. NOTE: If a backlog occurs for TRIAGE the queueing discipline is FIFO.

Assumptions:

1. Forecasts of asset allocations only considers personnel or equipment available at the current maintenance entity processing the MAINTDMD. Forward deployment of personnel or equipment from supporting maintenance entities is not considered.
2. Controlled exchange is not conducted at company level and cannibalization is only conducted by direct support (DS) level maintenance entities at brigade level or higher.
3. Perfect information is available for forecasting purposes.

4. TRIAGE is conducted instantaneously - no time is used. The time required for actual triage is included in repair time determinations by the REPAIR execution process.
5. This process ignores contamination of equipment problems.
6. Travel time from maintenance entity to disabled weapon system is negligible e.g. from company trains to combat positions is about one kilometer maximum and from other maintenance entities to their UERP or MCP is less than two or three kilometers.
7. There are two type of demands - report and recovery request.
8. There are no cancellations of maintenance demands.
9. The Heavy, Light, and Missile Maintenance Companies at division are aggregated into a single maintenance entity for triage purposes.

Processing:

1. TRIAGE firsts increments the maintenance entity's TOTAL DEMAND COUNT by one.
2. Then TRIAGE checks the DEMANDTYPE of the MAINTDMD. If the DEMANDTYPE is a recovery request then go to the recovery allocation steps (steps 15-18).
3. Next TRIAGE determines if the MAINTDMD is repairable. This is accomplished by finding the ERC of the MAINTDMD in the REPAIRABILITY List and extracting its repairability code - RC. The RC attribute of the MAINTDMD is set appropriately. NOTE: (For battalion or brigade level maintenance entity only: If DEMANDTYPE is repair request this step is skipped.) If the RC of the MAINTDMD is nonrepairable, TRIAGE sets the SALVAGE attribute switch of the MAINTDMD on

and goes to the recovery allocation steps (steps 15-18). NOTE: (For brigade or higher level maintenance entities only: An evacuation request is sent to the transportation module of the combat model instead of going to the recovery allocation steps.)

4. Next TRIAGE determines the repair level (RL) of the MAINTDMD by searching the REPAIR LEVEL List and matching the ERC of the MAINTDMD to the appropriate RL and sets the RL attribute of the MAINTDMD. NOTE: (For battalion or higher level only: If the DEMANDTYPE of the MAINTDMD is repair request and its RL is not null, this step is skipped.)
   a) (For company level only) If RL is higher than organizational level, TRIAGE goes to the recovery allocation steps (steps 15-18).
   b) (For battalion level only) If RL is higher than direct support level, TRIAGE goes to the recovery allocation steps (steps 15-18).
   c) (For brigade level or higher) If RL is higher than direct support level, TRIAGE generates an evacuation request which is sent to the TRANSPORTATION Module of the combat model.
5. Next TRIAGE determines the expected repair time in manhours under the condition of all parts and manpower being on hand for each personnel type k required for the MAINTDMD and the required number of each personnel type k - CMTTR(k) and NM(k). These MAINTDMD attribute values are found by searching the REPAIR TIME List and matching the ERC of the MAINTDMD to the appropriate CMTTR(k)s and NM(k)s. Also the PERSTYPE attribute of the MAINTDMD set to a list of all the personnel types k required and the DEMAND COUNT(k) is incremented by one for each k. NOTE: (For battalion level or higher: If the DEMANDTYPE of

the MAINTDMD is repair request and its CMTTR and NM attributes are not null, this step is skipped.)

6. TRIAGE next determines the conditional repair time for each personnel type k - CRT(k) - in clock hours according to equation C.1 and sets the CRT(k) attributes of MAINTDMD.

$$CRT(k) = CMTTR(k)/NM(k) \tag{C.1}$$

7. TRIAGE then conducts a first cut feasibility check to determine whether to repair the MAINTDMD at the current maintenance entity or to recover it to the supporting maintenance entity. This is accomplished by comparing each CRT(k) of MAINTDMD to the matching MTC(k) of the current maintenance entity. If any CRT(k) > its matching MTC(k), TRIAGE goes to the recovery allocation steps (steps 15-18). NOTE: (For brigade level or higher: The same comparison is made as above, however if any MTC(k) is exceeded, TRIAGE generates an evacuation request which is sent to the TRANSPORTATION Module of the combat model.)
8. TRIAGE next checks for repair parts availability by searching the REPAIR PARTS List and matching the ERC of the MAINTDMD to the appropriate set of repair parts codes - RP - and quantities - RPQ(RP) and sets the RP and RPQ attributes of the MAINTDMD. Then the process searches the maintenance entity's PARTS STOCKAGE List (PLL or ASL) and determines if the needed parts are on hand.
   a) If a needed part is on hand, the forecasted part acquisition time for the part - FPAT(RP) - attribute of the MAINTDMD is set to zero.
   b) (For company level only) If any parts are not on hand the process goes to the recovery allocation steps (steps 15-18).

c) (For battalion level only) If a needed part is not on hand, the process then checks the SALVAGE COMPATIBILITY List and matches each RP not on hand to compatible ERCs for the purpose of conducting controlled exchange to obtain the required parts. Then the maintenance entity's WAITING RECOVERY List is searched for MAINTDMDs with appropriate ERCs until a maximum number of the needed parts are matched to MAINTDMDs waiting recovery. This search matches RPs to MAINTDMDs according to the following priority scheme: first all MAINTDMDs with an on SALVAGE switch are searched, then all MAINTDMDs with an RL higher than the current maintenance entity's RL are searched. For each RP matched for controlled exchange, a CEPAT(RP) - controlled exchange part acquisition time - is obtained by searching the PART INSTALLATION AND REMOVAL List and a controlled exchange pointer - CEPTR - is assigned to the candidate MAINTDMD. A total controlled exchange part acquisition time for each personnel type k - TCEPAT(k) - is calculated according to equation C.2,

$$TCEPAT(k) = \sum_{KRP} (CEPAT(RP) \times 2 \times RPQ(RP)) \qquad (C.2)$$

where KRP is the set of all RP which require personnel type k for installation. The CEPAT(RP) is doubled in the calculation since controlled exchange involves the actual removal of the needed repair part from the candidate parts source and its replacement on that parts source with the unserviceable part from the item needing the repair part. The TCEPAT(k) attributes of the MAINTDMD are then set. For those required RP which have been matched for controlled exchange, the process calls the PART ACQUISITION FORECAST process of the SUPPLY Module to determine the order and ship time for each of these parts - OST(RP). Then a forecasted part acquisition time for each personnel type k - FPAT(k) - is calculated according to equation C.3,

$$FPAT(k) = \max_{KRP} \{OST(RP)\} \qquad (C.3)$$

where KRP is the set of RP requiring personnel type k for installation. The FPAT(k) attributes of the MAINTDMD are then set.

d) (For brigade level or higher only) The previous battalion steps for controlled exchange are conducted, however in this case the purpose is cannibalization. The only change in the battalion level steps is that, TCEPAT(k) is calculated according to equation C.4,

$$TCEPAT(k) = \sum_{KRP} (CEPAT(RP) \times RPQ(RP)) \qquad (C.4)$$

where KRP is the set of RP requiring personnel type k for installation. The CEPAT(RP) is not doubled in this case since cannibalization does not require a replacement for the acquired repair part.

9. TRIAGE then forecasts the clock hours until completion of the MAINTDMD for each personnel type k if the MAINTDMD were repaired at the current maintenance entity with assets under its control. First the MAINTDMD is placed on the maintenance entity's WAITING COMPLETION List and its list position determined according to the following nested MAINTDMD queueing discipline:

a) In progress demands before all other demands.
b) (For batalion level or higher) By unit priority.
c) By equipment priority.
d) By waiting repair followed by waiting repair and parts.
e) FIFO.

10. After the MAINTDMD's list position is determined, its expected time of completion for each personnel type - ETC(k) - is calculated according to the following steps.

    a) For each personnel type k needed for the repair of the MAINTDMD, set the in progress workload hours for personnel type k - IWLH(k) - attribute of the maintenance entity according to equation C.5,

    $$IWLH(k) = (CRT(k)+CEPAT(k))-(CT-ST) \qquad (C.5)$$

    where CT is the current time and ST is the start time of the repair.

    b) Then determine the waiting workload hours for each personnel type - WWLH(k) - according to equation C.6,

    $$WWLH(k) = \sum_{DW} (CRT(k) + TCEPAT(k)) \qquad (C.6)$$

    where DW is the set of MAINTDMDs waiting repair.

    c) Next the forecasted repair time for each personnel type k - FRT(k) - required for the MAINTDMD is calculated according to equation C.7,

    $$FRT(k) = 24 \times ((IWLH(k)+WWLH(k)+CRT(k)+TCEPAT(k))/TDCH(k)) \qquad (C.7)$$

where CRT(k) and TCEPAT(k) are the attributes of the MAINTDMD being processed and TDCH(k) is the total daily clock hours for personnel type capability of the maintenance entity. TDCH(k) is calculated according to equation C.8,

$$TDCH(k) = QP(k) \times 24 \times PWF \qquad (C.8)$$

where QP(k) is the quantity of personnel type k in the maintenance entity and PWF is the productive work fraction attribute of the maintenance entity.

d) Then each ETC(k) is calculated according to equation C.9.

$$ETC(k) = FRT(k) + FPAT(k) \qquad (C.9)$$

11. TRIAGE next conducts the final feasibility check by comparing all ETC(k) of the MAINTDMD to the maintenance entity's forecasted movement time - FMT - and MTC(k) attributes. If any ETC(k) is greater than FMT or its matching MTC(k), the process goes to the recovery allocation steps (steps 15-18).
12. Otherwise the process then schedules the appropriate REPAIR or REPAIR PARTS SUPPLY execution processes as follows. If all FPAT(k) and TCEPAT(k) of the MAINTDMD equal zero, the process schedules the REPAIR process by placing the MAINTDMD on the maintenance entity's WAITING REPAIR List.
    a) If all FPAT(k) equal zero and any TCEPAT(k) are not zero, the process finds the matching CEPTRs and temporarily removes these MAINTDMDs from the WAITING RECOVERY List of the maintenance entity and places them on the WAITING CE List and schedules the REPAIR process for the MAINTDMD being

processed by placing it on the maintenance entity's WAITING REPAIR List and sets its CE - controlled attribute switch - on.

b) If any FPAT(k) are not zero, the process finds all appropriate RP using the set KRP and matching RP attributes of the MAINTDMD and schedules requisition of each of these RP in quantity RPQ(RP) by calling the REPAIR PARTS SUPPLY execution process and places the MAINTDMD on the maintenance entity's WAITING PARTS List with its waiting parts attribute - WP - on. If any TCEPAT(k) also are not zero the CE switch attribute of the MAINTDMD is set on and all MAINTDMDs on the maintenance entity's WAITING RECOVERY List which match the CEPTRs are temporarily removed from this list and placed on the WAITING CE List.

13. The process next checks the need to call for a periodic workload prioritization. If mod (TOTAL DEMAND COUNT / N) = 0 , the process calls the WORKLOAD PRIORITIIZATION process.

14. The process next checks the count of demands for each personnel types required for the processed MAINTDMD. For each DEMAND COUNT(k) which is greater than N, calculate the current maintenance workload in manhours for that personnel type - CWLH(k) - according to equation C.10,

$$CWLH(k) = IWLH(k) + \sum_{DW} (CRT(k) + TCEPAT(k)) \qquad (C.10)$$

where DW is the set of all MAINTDMDs on the maintenance entity's WAITING COMPLETION List not in progress. The process then calls the MAINTENANCE TIME CRITERIA UPDATE process.

15. Stop.

16. The following steps are the recovery allocation steps of TRIAGE. First determine the recovery vehicle type - RVT - needed for the MAINTDMD's equipment type - ET - attribute by searching the RECOVERY COMPATIBILITY List and matching the ET to a set of appropriate RVTs and set the RVT attribute of the MAINTDMD to this set. If a matching RVT from this set is not found on the maintenance entity's recovery asset list (this includes all organic, attached, and OPCON assets) attribute, the process places the MAINTDMD on the maintenance entity's WAITING RECOVERY List and sets the MAINTDMD's DEMANDTYPE to recovery request. Then the process generates an identical MAINTDMD with DEMANDTYPE of recovery request to the supporting maintenance entity.

17. If an acceptable RVT is in the maintenance entity's recovery asset list attribute, the MAINTDMD is placed on the entity's WAITING RECOVERY List according to the following nested queueing discipline and its list position determined:

    a) In progress, then waiting recovery, then supporting recovery request.
    b) (For battalion level of higher) By unit priority.
    c) By equipment priority.
    d) Repairable, then salvage.
    e) FIFO.

18. Then the process calls the TRANSPORTATION Module to obtain a forecasted travel time for the recovery mission (from the maintenance entity's location to the supporting maintenance entity's maintenance collection point or UERP location) - RECT. Next the maintenance entity's recovery workload hours for recovery vehicle type RVT is determined according to equation C.11,

$$RWLH(RVT) = \sum_{IRD} (RECT(RVT) - ST) + \sum_{WRD} RECT(RVT) \quad (C.11)$$

where IRD is the set of in progress MAINTDMD for recovery and WRD is the set of waiting MAINTDMD for recovery which precede the WAITING RECOVERY List position of the MAINTDMD in process. The expected recovery completion time - ERT - is then calculated according to equation C.12,

$$ERT = 24 \times ((RWLH(RVT) + RECT(RVT)) / TDRH(RVT)) \quad (C.12)$$

where TDRH(RVT) is the total daily recovery hours capability for recovery vehicle type RVT of the maintenance entity. TDRH(RVT) is calculated according to equation C.13,

$$TDRH(RVT) = QRV(RVT) \times 24 \times PWF \quad (C.13)$$

where QRV(RVT) is the quantity of operational recovery vehicles of type RVT in the maintenance entity and PWF is the maintenance entity's productive work fraction.

19. The process then makes a feasibility check to determine whether to recover the MAINTDMD with available assets or generate a recovery request to the supporting maintenance entity by comparing the ERT to the maintenance entity's recovery time criteria - RTC. If ERT is greater than RTC, the process places the MAINTDMD on the maintenance entity's WAITING RECOVERY List and sets the DEMANDTYPE to recovery request and generates and identical MAINTDMD to the supporting maintenance entity with a DEMANDTYPE of recovery request. Otherwise the process schedules

the RECOVERY execution process by placing the MAINTDMD on the maintenance entity's WAITING RECOVERY List.

20. Stop.

B. WORKLOAD PRIORITIZATION PROCESS

PROCESS: WORKLOAD PRIORITIZATION

Activated by: a change in the supported hierarchy's mission posture or the generation of every Nth demand at a particular maintenance entity.

Given:

1. Maintenance entity identifier - j
2. Input type - mission posture change or Nth demand

Description:

This process updates both the unit and equipment maintenance priorities at a specific maintenance entity.

Processing:

1. The process first checks the maintenance entity's hierarchical level - HL. If HL is company level step 2 is skipped.
2. The process next updates the maintenance entity's UNIT MAINTENANCE PRIORITY List attribute by setting it equal to the supported hierarchy's TACTICAL UNIT PRIORITY List.
3. The process then updates the maintenance entity's EQUIPMENT MAINTENANCE PRIORITY List attribute by ordering the supported equipment types according to the following nested scheme: first the supported entities' pacing (primary weapon systems) items ordered by unit priority, then all other equipment types in increasing order of equipment operational readiness rates aggregated at the supported hierarchy level - OR(ET).

4. Stop.

C. MAINTENANCE TIME CRITERIA UPDATE PROCESS

PROCESS: MAINTENANCE TIME CRITERIA UPDATE

Activated by:

1. A change in mission posture of the supported hierarchical entity.
2. The generation of the Nth demand for a personnel type k at a maintenance entity.
3. The occurrence of a work capability change time due to forecasted entity movement.

Given:

1. Maintenance entity identifier - j.
2. Set of personnel types - k.
3. Input type - mission posture change, periodic, work capability change.

Description:

The Maintenance Time Criteria Update process makes the decision update of the initially established set of MTC(k) of a maintenance entity. This update is accomplished by use of one of three methods based upon the type input to the process.

Assumptions:

The initial set of MTC(k) are initialized for each maintenance entity as part of the combat model initialization process.

Processing:

1. The process first determines the input type (mission change, periodic, work capability change) - INTYPE. If the INTYPE is mission change go to step 2. If the INTYPE is periodic go to step 3. If the INTYPE is work capability change go to step 4.

2. Using the complete set of personnel types k of the maintenance entity, the MISSION POSTURE MTC List is searched and matches the input MP - mission posture - of the supporting hierarchical entity to the appropriate set of MTC(k)s. The MTC(k) attributes of the maintenance entity are then set to these new values. Go to step 5.
3. Using the input set of personnel type or types k, obtain the matching acceptable workload deviation for each type k - AWLDEV(k) - attributes of the maintenance entity. Then for each input k calculate the workload capability - WLC(k) - according to equation C.14,

   $$WLC(k) = QP(k) \times 24 \times PWF \qquad (C.14)$$

   where QP(k) is the current quantity of personnel type k in the maintenance entity and PWF is the maintenance entity's productive work fraction. The process then calculates the upper and lower workload thresholds for each personnel type - UWLT(k) and LWLT(k) - according to equation C.15 and equation C.16.

   $$LWLT(k) = WLC(k) - AWLDEV(k) \qquad (C.15)$$

   $$UWLT(k) = WLC(k) + AWLDEV(k) \qquad (C.16)$$

   The process then checks to see if any current workload for the set of personnel types - CWLH(k) - violates either of its workload thresholds. If any CWLH(k) is greater than its matching UWLT(k) then update the matching MTC(k) according to equation C.17.

$$\mathrm{MTC}(k)=\mathrm{MTC}(k)\times(1-((\mathrm{CWLH}(k)-\mathrm{WLC}(k))/\mathrm{WLC}(k))) \qquad (\mathrm{C.17})$$

If any CWLH(k) is less than its matching LWLT(k) update its matching MTC(k) according to equation C.18.

$$\mathrm{MTC}(k)=\mathrm{MTC}(k)\times(1+((\mathrm{WLC}(k)-\mathrm{LWLT}(k))/\mathrm{WLC}(k))) \qquad (\mathrm{C.18})$$

Go to step 5.

4. Using the input work capability change number due to forecasted movement - WCCNBR - for the maintenance entity find the matching work change fraction - WCF - by searching the MOVEMENT WORK CHANGE List and matching the entity type to a set of work capability time change fractions and times. Then update the MTC(k) for all k in the maintenance entity according to equation C.19.

   $$\mathrm{MTC}(k) = \mathrm{MTC}(k) \times \mathrm{WCF} \qquad (\mathrm{C.19})$$

   Go to step 6.
5. Set the DEMAND COUNT(k) to zero.
6. Stop

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